AVIATION
LECTRICIAN'S
MATE 1 & C

AVY TRAINING COURSES

AVIATION ELECTRICIAN'S MATE 1 & C

PREPARED BY

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10349

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

PREFACE

This Navy Training Course is written primarily for Aviation Electrician's Mates of the U.S. Navy and Naval Reserve who are preparing for advancement to AE1 and AEC. It is one of a series of courses written especially for the enlisted Aviation Electrician's Mate. In addition to preparing the AE for his advancement examination, it will also help to improve his daily working proficiency.

The *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised), has been used as a guide in the selection of content for this training course. These qualifications are included in the back of this course as appendix III and are current through Change 12 to the manual. You should become familiar with these qualifications prior to starting work on this training course.

This course contains 14 chapters. All of these, with the exception of chapter 1, are concerned with the technical aspects of the AE rating. Chapter 1 contains introductory information, and you should become familiar with the contents of this chapter prior to your study of the other chapters.

As one of the Navy Training Courses, this book has been prepared by the U. S. Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit is also given to the Aviation Electrician's Mate School, Jacksonville, Florida, for preparation of the end-of-chapter questions.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E–2 or 8 mos. total service.	6 mos. as E–3 or 14 mos. total service.	12 mos. as E–4.	12 mos. as E–5; total service at least 36 mos.	36 mos. as E–6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E–3 and all PO advancements.				
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Blueprint Reading and Sketching, NavPers 10077-A
First Aid Standard Training Course, NavPers 10081
Basic Hand Tool Skills, NavPers 10085
Basic Electricity, NavPers 10086
Basic Electronics, NavPers 10087
AE 3 & 2, NavPers 10348

USAFI TEXTS

The United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial listing of those courses applicable to your rate follows:

Correspondence

Number	Title
MC 164	Beginning Algebra I
MC 165	Beginning Algebra II
MB 188	Trigonometry
MC 290	Physics I
MC 291	Physics II

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CONTENTS

STUDY GUIDE

Since this training course has been written primarily for the AE General Service Rating, all its contents are pertinent to those men who are advancing in the AE rating. Most of its contents are also pertinent to the qualifications required for the Emergency Service Ratings AEM and AEI. The exceptions are that AEI's may omit chapters 11, 12, and 13. They may also omit the sections of chapter 5 that treat voltage and speed controls of generators and inverters, and the sections of chapter 6 that treat protective devices used in a-c distribution systems. AEM's may omit the section of chapter 9 that treats the testing, adjusting, and repairing of electronic components used in instrument, automatic flight systems, and instrument-type indicating and warning systems.

The following table indicates which chapters of this training course apply to your rating. To determine the sections of this course that you should study, use the following procedure:

1. Select the column that applies to your rating. If you are advancing in the General Service Rating, you will use the column headed "AE." If you are advancing in one of the Emergency Service Ratings, you will use either the column headed "AEM" or "AEI."

2. To the right of each chapter number appear rating level designations, each designation falling under a particular rating heading (AE, AEM, AEI). When the rate for which you are preparing to advance appears to the right of a given chapter, you should study that chapter.

3. These chapters contain information which will assist you in meeting the qualifications for your rating. In order to gain a well-rounded view of the duties of the General Service Rating, it is recommended that you read the other chapters of this course even though they do not pertain directly to your rating.

Chapter	AE	AEM	AEI
1	1, C	1, C	1, C
2	1, C	1, C	1, C
3	1, C	1, C	1, C

Chapter	AE	AEM	AEI
4	1, C	1, C	1, C
5	1, C	1, C	1, C
6	1, C	1, C	1, C
7	1, C	1, C	C
8	1, C	1, C	1, C
9	1, C	1, C	C
10	1, C	1, C	1, C
11	1, C	1, C	---
12	1, C	1, C	---
13	1, C	1, C	---
14	1, C	1, C	1, C

AVIATION ELECTRICIAN'S MATE 1 & C

CHAPTER 1

DUTIES AND RESPONSIBILITIES

As a part of the Navy's training program, this Navy Training Course is written for the purpose of aiding you to prepare for advancement in rating. In order to meet the requirements for advancement you must have gained a wide background of practical experience in the field of aviation electricity, and you must also possess a thorough knowledge of electricity from the standpoint of theory. Your past years of naval experience have afforded you an opportunity to equip yourself with much of the knowledge and many of the skills that will be of valuable assistance as you progress in your naval work. You should become thoroughly familiar with the contents of the Navy Training Courses given in the preface of this course; for these are essentially prerequisites to the publication that you are now going to study.

ADVANCEMENT IN RATING

Advancing to AE1 or AEC means much more than an increase in pay and the acquiring of the privileges of a first class or chief petty officer. This step up the Navy ladder of success means that you must increase your knowledge and skills as they relate to your field. You must assume the responsibility of training men as they advance in the field of naval electricity. Also, it means that much of your time will be devoted to work of a supervisory nature, and in doing this you will be required to assume duties that are somewhat new. You will be required

to make decisions; for in many situations you will be in charge of the electrical department of an activity or squadron.

You should be able to perform all of the professional jobs that are required of an Aviation Electrician. Unless you can perform these jobs you cannot expect to command the respect of your men and your officers. You must be able to lead, supervise, and train men; organize and administer electric shops engaged in the maintenance and repair of electrical equipment; and stow, preserve, and account for supplies and spare parts.

There are several good reasons for advancing in rating. Some of these are primarily advantageous to the individual and others are primarily advantageous to the Navy.

You profit personally from the additional ability that you derive from the study and other efforts that you must make in order to advance. You are a better educated and trained man. It is a boost to your pride and morale to be able to do your job better and to understand more completely the various aspects of your rating. Also, it pays you monetarily. You have more means to support yourself, your family, thereby providing a higher standard of living. You have a feeling of accomplishment since you know that you are getting ahead in your chosen career field. By climbing farther up the leadership ladder, you are in a better position to lead and guide the efforts of others, watching them grow and develop into efficient workmen and finer individuals.

The Navy also profits as personnel advance in rating, since they can render greater benefit to their branch of military service. Personnel are better qualified and are able to perform their duties more efficiently; they can give better training to others, and they can more effectively discharge their increasing responsibilities in connection with the management functions of supervision. They move up to replace those who have been promoted or retired, thereby making room for the individual who wants to move into their position; that alone is good for the morale of all concerned. As a result, the Navy has better trained and happier personnel.

Training Courses

Navy Training Courses are written to provide enlisted personnel with training information needed to qualify for advancement. They are organized in such manner that they may be used with a minimum of supervision. It is recognized that no book is a substitute for actual experience. However, many of the men who desire to advance in rating do not have the opportunity to work at their specific job and must depend on training courses as their source of information. For this reason, Navy Training Courses are designed as self-study texts with a maximum of illustrations and with the text written in readable and conversational style.

This Training Course

In the performance of practical work, proficiency comes with practice and experience, for which no book, however helpful, can be an adequate substitute. On the other hand, you will find, in preparing for the written examination, that no amount of proficiency in practical work can take the place of the knowledge on which you may be examined. This course has been prepared to assist you in acquiring the knowledge that you will need in order to pass the exam for advancement to AE1 and AEC. It is designed to give appropriate personnel the sort of self-study help that they need, especially in those cases where there is little opportunity for a well-conducted training program or little chance of attending a service school.

CONTENTS.—There are 14 chapters in this training course. This chapter is an introduction to the course. It is nontechnical in nature and is for the purpose of introducing you to the course. It sets forth your duties as a senior petty officer, describes the types of assignments that you may expect to fill, and explains the meaning of the various qualifications that you must fulfill in order to advance in rating. It describes some of the publications that you should refer to when studying for advancement and lists some general suggestions for study. Squadron or activity organization is discussed, along with the various maintenance levels and the tasks that are to

be accomplished at each level. Duties of the senior petty officer are discussed from the standpoints of the preparation and maintenance of logs, records, and reports; shop administration, and training the men under you.

The other chapters deal with the technical aspects of the rates of Aviation Electrician's Mate, First Class and Chief. Chapter 2 deals with the problems and responsibilities that relate to supply on the shop level; it also discusses many of the publications with which you should be familiar. Advanced alternating-current theory is presented in chapters 3 and 4. These deal with vector representation of voltages and currents, power, polar notation, polyphase power systems, delta and wye systems, Millman's Theorem, and three-phase unbalanced systems. Chapter 5 is an introduction to magnetic amplifiers which covers the basic principles of operation, basic circuits, applications, and advantages and disadvantages. Chapter 6 deals with the generation, control, distribution, and system protection for aircraft a-c power installations. The most advanced types of a-c machinery are discussed. The applications of servomechanisms to aircraft electrical systems along with a discussion of data transmission systems, servo amplifiers, and servomotors are given in chapter 7.

Chapter 8 is an introduction to transistors; it deals with semiconductors, junctions, characteristics of transistors, basic transistor circuits, and applications. Aircraft compass systems are discussed in chapter 9. The MA-1 compass system is discussed in detail with major emphasis being placed on the various units that make up the system. Chapter 10 deals with automatic flight control and stabilization systems. Automatic pilots are discussed along with the various units and sets that are used in connection with automatic flight. Pressurization and cabin temperature control for aircraft is discussed in chapter 11. Typical system operation is described along with servicing and inspecting. Chapter 12 deals with propeller synchronization. Synchronizers are described along with the operation that takes place during on-speed, overspeed, and underspeed conditions. Chapter 13 is devoted to d-c control, protective, and warning devices. Discussion is given to various types of control and protective relays, ground and feeder

protection, motor controls, and warning devices. The last chapter presents information on special equipment, maintenance problems, and special maintenance techniques.

Besides the chapters described above, the preliminary part of the course includes a reading list, study guide, table of contents, preface, and the credo. At the end of each chapter there is a quiz, which you should use in your review of the chapters. In the back part of the course you will find the answers to the quizzes and the qualifications for advancement in the Aviation Electrician's Mate rating. Also, the course contains an index.

HOW TO USE THIS COURSE.—Proper use of this training course will greatly aid you in preparing for advancement in rating to Aviation Electrician's Mate, First Class and Chief. Some individuals may make the mistake of merely studying the answers to the end-of-chapter quizzes. The ones who do this will not obtain much benefit from the course. As the examination for advancement will contain questions not included in the end-of-chapter quizzes, the persons who study the text material thoroughly will find themselves better qualified to pass the examination.

Since you have advanced to Aviation Electrician's Mate, Second Class or First Class, you may have already adopted a method for using course material similar to this. However, the following method will provide you with a procedure that will enable this course to be used to the best advantage.

When you begin studying this course, turn to the table of contents to learn the page number of the appendix that lists the "quals" requirements. Carefully study the qualifications required of the rate to which you are advancing. Also, remember that you are held responsible for the requirements of all rates below the rate to which you are advancing. After you have learned what knowledges are listed as required qualifications for advancement, turn to the study guide. It will indicate whether you are to study all chapters or just certain ones. Study the applicable chapters, mastering the subject matter of each before proceeding to the next.

When you think you have mastered the material of a chapter, turn to the end-of-chapter quiz. Indicate your

answers on a separate piece of paper. Then turn to the answers in the appendix and check your responses. If some of your answers are incorrect, there may be one of several reasons for it. You may not have studied the material that the text items cover sufficiently to master it. Another possibility is that you failed to read the test items carefully and completely. You should study again all the material covered by test items that you answered incorrectly due to lack of understanding or failure to master the subject matter.

NOTE: Ability to answer all the questions of all the quizzes does not necessarily mean that you have mastered all the subject matter. The quizzes will help you to review much of the material, but they are no substitute for mastery of the material page by page.

As you study the material in this training course, you will find it helpful to read other references on the subject. Some of the most important of these are included in the reading list in the front of this book.

In connection with reference material, you should become familiar with a BuPers publication titled *Training Publications for Advancement in Rating*, NavPers 10052. The NavPers number is followed by a letter suffix which indicates the date of publication; presently the latest issue is NavPers 10052(F). This publication is a bibliography of Navy Training Courses and other publications required or recommended for study by naval personnel who are preparing for advancement. Publications are listed for each rating and provide a working list of material for enlisted personnel to study in preparation for qualification in the duties of the various rate levels of that rating. Training courses marked by an asterisk must be completed for specific rate levels before you are eligible to take the advancement examination. It must be realized that, as indicated in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised), all higher pay grades listed in this booklet may be held responsible for the materials in the publications listed for the lower rates of that particular rating.

Since in many instances only pertinent sections of publications are listed in the *Training Publications for Advancement in Rating* the most effective use will be made of this booklet by concurrent reference to the QUALS

MANUAL. Here again, it must be assured that the latest change to the manual is being used.

MILITARY LEADER AND TECHNICAL SPECIALIST

As a Navy petty officer you are both a military leader and a technical specialist. In your work, of course, these two phases go together. As a petty officer, you have certain general or military duties; and as a specialist, you have certain professional or technical duties. And you are responsible for attaining proficiency in both phases of a petty officer's work. This course deals primarily with your specialist or technical (professional) duties. However, both type duties will be discussed.

MILITARY DUTIES

Leadership

Since you have been a petty officer for some time, you realize that more leadership is required of the higher rates. Not only are you required to have superior knowledge, but you are also required to have the ability to handle personnel. This ability increases in importance as you advance through the various rates as a petty officer. More and more your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates rather than how much of the actual work you do yourself. You will be required to perform the composite role of master technician, leader, supervisor, inspector, and instructor.

Leadership involves organizing the activities of group members toward the accomplishment of a given task. Successful leadership, like anything else, takes practice. Be willing to accept responsibility and you will find yourself enjoying responsibility. Make yourself a leader your men will gladly follow. From their respectful attitude toward you, you will get a strong sense of satisfaction.

Much of what is presented in subsequent paragraphs is written in terms of shop supervision; this information applies equally to leadership. In fact, supervision is an aspect of leadership. It is the technique by which you intelligently guide the activities of your men.

Good organization provides the structure through which plans are formulated, clear cut lines of communication are established, authority and responsibility are delegated, quality and quantity of work are achieved, materials are procured, and missions are accomplished. The organizational structure in which you function depends on the type of duty to which you are assigned.

No matter what the type of organizational structure, the senior AE should know the following:

1. To whom you and your men are directly responsible.
2. Where you can go for advice and assistance.
3. Where your orders and assignments originate.
4. Exactly what your superiors expect from you.
5. Just what your men and equipment are capable of doing.

As a supervisor you will occupy an important position in the maintenance department of your activity or squadron. You will be the link in the chain of command between your officers and your men. Consequently, you must be thoroughly familiar with the organization of your activity or squadron.

Supervisory Techniques

DISCIPLINE.—As a leading AE it is your responsibility to organize your shop and men so that the tasks of the electric and instrument shop can be accomplished with speed and accuracy. The duties and responsibilities of each man are spelled out in detail within a good organization. Each man knows exactly what is expected of him. However, you know from past experience that the mere listing of duties does not necessarily get the job done.

The established routine of work activity must be reinforced by discipline. The leading AE's problems of supervision and maintenance of discipline are complicated because in this category you are dealing with human beings and not the inanimate mechanical or electrical components of a piece of equipment. This means that you must supervise in a calm and understanding manner to get prompt and willing compliance with orders. You will command more respect and get better results by being reasonable and fair. Fairness is not to be confused with laxity or undue leniency.

ROUTINE PROCEDURE.—Be certain that your men know what is expected of them. You can not expect anyone to do a satisfactory job unless his instructions are clear. You should have a standard operating procedure for all routine tasks. Have all of the men learn these procedures thoroughly. In certain complex or dangerous operations no deviation from the standard procedure should be permitted. However, if a man can perform his work satisfactorily by a method different from yours, and if his method is at least as fast, safe, and efficient, let him do the job his way. In fact, you will be wise to encourage any suggestions which might improve the quantity, quality, safety, or economy of the work.

In scheduling your work, remember that your men will need occasional breaks and periods of relaxation. If the factor of fatigue is not taken into consideration, work will fall behind schedule. On the other hand, if you grant an excessive number of breaks, you may lose control over your men. You must strive for a happy medium in each situation, and be flexible enough to allow for changing conditions. Make the standards of conduct consistent for everyone working under your supervision. Favoritism should never be shown.

PRAISE AND CENSURE.—There is a common misconception that discipline is merely a matter of administering censure or punishment. Discipline also has its positive aspects that all too often are overlooked. When inspecting the quality of work done by your men, you must resist the tendency to comment only on the mistakes that are made. You should comment favorably on the outstanding aspects of the job as well. Here too, you must use good judgement. No one is entitled to extra praise for doing a job well because that is his job. Nevertheless, proper comment goes a long way in boosting morale. However, excessive flattery should be avoided.

When your superiors comment favorably about work performed in your division, the information should be passed on to the men who helped earn the commendation. Do not leave the impression that you are due all of the credit. Another good rule to remember is praise in public, censure in private. When censure is necessary, be careful that the man understands why he is being censured. Be especially careful to avoid the use of

sarcasm. If one of your men makes a mistake do not lose your temper. This NEVER does any good. If a man has misunderstood an order, a technique, or a principle, take steps to insure that future directions are given more clearly.

PERSONNEL RELATIONSHIPS.—True discipline is obtained through the voluntary cooperation of the men with their leader. It should be recognized that cooperation is a two-way proposition. The men depend on the leader to fulfill many of their psychological needs. They look to the leader for the security of his approval. They want a supervisor whom they can respect and brag about, and you, as the leading AE, want a crew that will be a credit to you, the AE shop, and the Navy. The relationship that you establish with your men is a reflection of your attitude toward them. If you know and understand them, have respect for their dignity as human beings, and show a sincere interest in their welfare, they will respond with renewed energy and with pride and confidence in your leadership. They will work because they want to and not because they are compelled to or because they fear punishment. This is what is meant by voluntary discipline. It is based on knowledge, reason, sense of duty, and loyalty, and is closely related to morale.

You should learn all you can about each member of your crew (their names, ambitions, problems, capabilities, and limitations). The men should know that you are sincerely interested in their welfare. Usually you should not volunteer advice on personal problems. However, a man with such problems often needs someone whom he respects to talk to. By simply being an understanding listener, it is possible to be of great help in such circumstances.

The men should be given an opportunity to get to know their leader. In this way a common ground of understanding is established. When work is to be done, you should be in the area. Your presence indicates that you know what is going on and are interested in what the men are doing. Except in emergencies, you should tell the men what to do rather than how to do it. In this way they will learn by doing.

You should be a good craftsman, and your skill must be reflected in the high quality of your own workmanship.

In fact, your work should set the example for others. Keep up with every new development, military and civilian, that might affect your work. If you are confronted with a question you cannot answer, admit it. No one person knows all the answers, so do not try to bluff. If the bluff does not work, you will lose the respect of your men. Instead, show your men that you have an inquiring mind. Make every effort to find the answer to the question and then share your knowledge with others in the shop. You will find that discipline becomes much easier if you show proficiency in your technical specialty.

As a first class or chief, you will frequently become involved in personnel problems, such as recommending men for promotion, and settling differences and grievances between them. You must handle such matters with discretion and fairness. Your job will put you in the role of a liaison man, for you will have to deal with equals and superiors as well as subordinates. Your attitude toward this chain of command is important since the whole structure of naval service is built upon ascending and descending responsibilities. Each officer and man in the Navy is dependent upon others for the smooth performance of his tasks.

The morale of men under you is an index to the efficiency of your shop. Attempt to detect small problems before they grow into large ones. Counsel with your men, give them advice and assistance whenever possible.

PROFESSIONAL DUTIES

The AE rating is a group of jobs which require essentially the same aptitudes, training, experience, skills and abilities. Your professional (technical) duties include those jobs which require you to use your special training relating to a particular field. As an AE your professional duties relate to those jobs that must be performed in maintaining and operating aircraft electrical and instrument equipment.

The rating of Aviation Electrician's Mate is divided into six rates or pay grades. The degree of complexity that the AE must face in connection with a job is determined by his rate. The higher the rate the greater the amount of responsibility that goes with the jobs required

of the particular rate. Appendix III of this training course is a DETAILED LISTING BY RATE of the jobs that AE's are required to perform.

The petty officer level of chief is now divided into three pay grades, E7, E8, and E9. This should serve as a considerable incentive to the men of the rating, since a person need no longer feel that he has reached the highest step of his enlisted career when he has advanced in rating to chief.

By now you should be thoroughly acquainted with the technical skills required of the Aviation Electrician's Mate, Third Class and Second Class. The most important additional skills required of you as a first class or chief are as follows:

1. Test, adjust, calibrate, install, and make authorized repairs to—
   a. Aircraft instruments.
   b. Power, lighting, and noninstrument type indicating and warning systems.
   c. Units of aircraft electrical systems including servos, relays, protective devices, and all rotating electrical equipment.
2. Maintain and test aircraft propeller and engine electric/electronic control systems.
3. Make performance test including bench, preflight, and required inflight adjustments to maintain proper operation of automatic pilot equipment.
4. Perform instrument repair, using required machines and special handtools.
5. Interpret wiring diagrams contained in *Handbooks of Maintenance Instructions* in troubleshooting electrical systems.
6. Analyze malfunctions and determine corrective action required on aircraft electrical and instrument systems.
7. Conduct on-the-job training and supervise personnel engaged in maintenance of aircraft electrical and instrument systems.
8. Furnish technical assistance in preparation of reports required by higher authority relating to electrical systems and/or equipment, including aircraft accident reports.

9. Organize and administer personnel and facilities for maintenance of aviation electrical and/or instrument systems.

10. Supervise the use, filing, and maintenance of publications and records; supervise preparation of reports required by own department.

11. Supervise the requisition and inventory of, and account for allowed materials in accordance with current directives.

12. Screen defective exchangeable electrical components and instruments, for feasibility of authorized local repair in lieu of exchange.

Your ability to perform the above listed skills is determined by a number of factors. The most important of these factors is the knowledge that you possess concerning a particular skill that you must perform. Navy Training Courses contain the information necessary for you to gain the knowledge in order to perform many of the technical duties of your rate. Insofar as possible, this training course, *AE 1 & C,* contains information required of First Class and Chief Aviation Electricians.

QUALIFICATIONS FOR ADVANCEMENT

The Manual of Qualifications for Advancement in Rating, NavPers 18068 (Revised), is of vital interest to the division officer and the enlisted man alike. This publication is the official manual which promulgates the minimum qualifications for the advancement in rating of enlisted personnel in the regular Navy and the Naval Reserve. It covers in more or less broad terms both the military and the professional requirements for advancement in all ratings in the Navy. The Bureau of Naval Personnel issues CHANGES to the quals manual in order to keep the requirements of your rating up to date. The qualifications printed in appendix III of this training course for the Aviation Electrician's Mate rating are current through change 12 only. It is important that you refer to the latest change to the quals manual when preparing for any advancement examination. This is the only way you can be certain that you are studying all of the requirements of your rating. Visit your information and education office or consult your education and training officer for information concerning the latest changes to the manual.

The naval rating structure is subject to continual review to insure the most effective manpower utilization and career patterns. Beginning with change 11, two different and distinct ratings structures will exist in the *Qualifications Manual* (NavPers 18068). These are the structures established in 1947 and a new structure established in 1957. The older structure will be replaced by the new structure on an evolutionary basis with ratings revised in terms of the new structure as rapidly as possible. At the time this training course is published, the AE rating is still operating under the structure established in 1947. It is suggested that you study the preface of the quals manual since it sets forth in detail the aspects of the two structures. The AM rating has already been changed to the new structure; it is suggested that you compare the AE and AM ratings as a means of better understanding the new structure. Following is a brief description of the two structures.

The 1947 structure provides for GENERAL SERVICE RATINGS and EMERGENCY SERVICE RATINGS. The general service ratings, which are for enlisted personnel of the regular Navy in time of peace provide for a petty officer broadly qualified in all aspects of his rating. The emergency service ratings, which are for personnel of the Naval Reserve in peacetime and for both the regular Navy and the Naval Reserve in wartime, provide the flexibility needed to permit expansion from the broad general service areas to the narrower service areas within the same occupational grouping.

In recent years the rapid introduction of complex technological developments in the Navy, as well as greater use of noncareer personnel, has produced a need for modifications to the 1947 structure. A structure is needed which will provide for specialization and reduce training time. The concept of the broadly trained and qualified petty officer is retained in the new structure and, at the same time, effective manpower utilization is insured by providing desirable specialization in the lower pay grades of certain ratings. Also, this new structure applies equally to both the regular Navy and the Naval Reserve and there is no change in an enlisted man's rating in the case of mobilization. The new structure

consists of (1) GENERAL RATINGS (2) SERVICE RATINGS, and (3) EMERGENCY RATINGS.

A general rating reflects qualifications in all aspects of an occupational field and insures broadly qualified senior petty officers. It is similar to and will replace the present general service rating and is applicable to both the regular Navy and the Naval Reserve. A service rating reflects qualifications in some of the aspects of an occupational field and provides specialization where deemed desirable. It is similar to and replaces the emergency service ratings for the Naval Reserve and also it is applicable to the regular Navy. An emergency rating reflects qualification in a civilian skill which is not identified in the peacetime Navy but is required to be identified in wartime. It is similar to and will replace the exclusive emergency service rating.

In summary, the new rating structure will provide (1) a completely integrated system applicable to both peacetime and wartime which undergoes no basic change in structure during mobilization, and (2) a structure with inherent incentives to provide necessary generalization at the senior pay grades and built-in flexibility to accommodate specialization in the lower pay grades where necessary.

Military Requirements

The military requirements that are required of you are listed in appendix III of this training course. These are taken from the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised). Military requirements are applicable to all enlisted men irrespective of rating. Three Navy Training Courses have been written which cover all of these requirements. They are *Basic Military Requirements*, NavPers 10054, *Military Requirements for Petty Officer 3 and 2,* NavPers 10056, and *Military Requirements for Petty Officer 1 and C,* NavPers 10057.

The basic course is written to cover the military requirements of the first three pay grades. It is concerned primarily with the meaning of military requirements, naval organization, military drill and ceremony, security, ABC warfare, naval aircraft, service records, and advancement and training.

Military Requirements for Petty Officers 3 and 2 is concerned primarily with the knowledge that a petty officer must possess in order to work independently and to assume leadership duties. Major topics covered are—importance of the U. S. Navy, naval career opportunities, military command and leadership, discipline and regulations, survival, communications, and training methods.

Military Requirements for Petty Officers 1 and C is written for the senior petty officer and is concerned with the knowledge necessary to become a successful leader. Since you are preparing for advancement to first class or chief, you should become thoroughly familiar with the contents of this course. Also, you are responsible for the material in the other two courses. This course sets forth the military requirements of senior petty officers. It presents inspirational material concerning your place in the Navy. It points out your responsibilities as an instructor, describes some proven teaching methods that you may use, and presents techniques that may be used in evaluating your men. The last two chapters of this course are devoted to leadership. They contain a listing of the "do's and don'ts" of leadership and give examples of leadership problems that are apt to arise and methods of solving them.

Professional Requirements

The professional requirements required are listed in appendix III of this training course. These are taken from the *Manual of Qualifications for Advancement in Rating*, NavPers 18068 (Revised) and are current through change 11. These are the professional (technical) qualifications required of Aviation Electricians to perform properly the duties of their particular rate. The most important of these requirements for the First Class and Chief Aviation Electrician are discussed in this chapter under the heading Professional Duties.

This training course (*AE 1 & C*) is written primarily to aid the AE1 and AEC in fulfilling his professional requirements. Three additional training courses that relate to your professional requirements and with which you should become thoroughly familiar are—*Basic Electricity*, NavPers 10086, *Basic Electronics*, NavPers 10087, and *AE 3 & 2*, NavPers 10348.

Record of Practical Factors

Practical factors are those skilled operations that you must be able to perform prior to your advancement. These are given in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised). They are also included in appendix III of this training course. The requirements listed under practical factors include the minimum skills and abilities that you should possess in order to advance.

Form NavPers 760(AE), *Record of Practical Factors,* lists the practical factor (military and professional) requirements for the Aviation Electrician's Mate rating. There is a similar form for all ratings. As you demonstrate proficiency in the required practical factors listed on this form, an entry is made which shows the date and the initials of the supervising officer. Instructions for completing this form are provided at the top of its first page.

Each man studying for advancement in rating should have a copy of this form for his personal record and guidance. A copy of this form is held by the division officer or other appropriate supervising officer for each man in pay grade E-3 through E-6. Upon transfer of an enlisted man, the supervising officer's copy of the form is signed, inserted in the correspondence side of the service record, and forwarded.

The appropriate items on NavPers Form 760(AE) must be completed before you are eligible to take the examination for advancement in rating. A few days prior to your advancement examination, you should check to see that the supervising officer's copy of your form 760 is or will be completed on time. Also, when you are being transferred to a new duty assignment you should check to see that all of the practical factors you have completed have been entered on your form 760.

Any major changes to the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised), require that the *Record of Practical Factors* form be reprinted. However, minor changes to the "quals" manual may be recorded in spaces provided in the form 760. The relationship between the quals manual and the form 760 is apparent, since the practical factor requirements printed

in the form 760 are taken directly from the manual. Form 760 affords an orderly and meaningful method of recording your progress in advancement towards the next higher rate within the rating.

SQUADRON OR ACTIVITY MAINTENANCE ORGANIZATION

As an Aviation Electrician's Mate, First Class or Chief, you will most likely be assigned to a billet that relates directly to the operation and maintenance of aircraft electrical and instrument equipment. Because of your past naval experience, you already know that your assignment possibilities cover a wide range of duties and responsibilities. The most common command billets to which AE's are assigned are operating squadrons, naval air stations, aircraft carriers or seaplane tenders, or a training billet in a technical school. Each of the foregoing command billets will assign you to specific duties within the command. Depending on the type command, you can expect certain types of duties within each.

In operating squadron and seaplane tender billets, you will most likely perform routine electrical maintenance. On an aircraft carrier, you will be in the V6 division, and your job will consist mainly of maintaining shop facilities, auxiliary power units, and test equipment to be used by the airgroup aboard. In a naval air station billet, your job possibilities are more varied. In most cases, however, you will either maintain aircraft assigned to the NAS, or work in an O and R department. When assigned to a training billet, you will most likely be an instructor, technical writer, or work in a testing section.

A more complete description of the functions of each type of command billet is given in chapter 1 of *AE 3 & 2*, NavPers 10348.

The maintenance organization of a squadron or activity is under the direction of a maintenance officer. As head of the maintenance department, he exercises administrative control over the department and is responsible to the commanding officer for the accomplishment of its mission. He establishes procedures and delegates authority to subordinates. He provides for review of decisions and

actions of his subordinates and controls assignments of personnel to divisions within the department. Each maintenance department will have an assistant head of the department. He implements the instructions and policies of the maintenance officer and acts for him in his absence.

Figure 1-1, shows a standard organization chart of the divisions that are controlled by the maintenance department. The code number prefixed by the letters AM stands for Aircraft Maintenance. Those divisions coded AM-11, AM-12, AM-13, AM-14, and AM-15 are staff divisions, while the divisions coded AM-2 through AM-7 are line divisions.

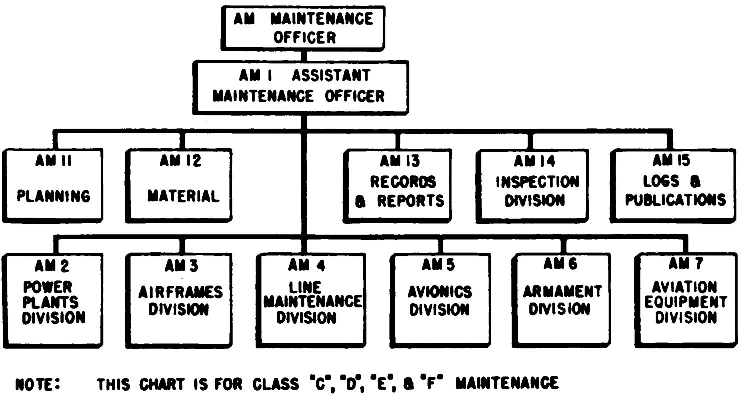


Figure 1-1.—Standard aircraft maintenance organization chart.

The line divisions are responsible for the ultimate accomplishment of the basic mission of the department. They normally contribute directly to the fulfillment of the broad objectives of the divisions and are dependent upon the staff branches for specialized advice and services. Each division has a division officer. He has administrative control over his division, under the direction of the maintenance officer. Division officers are responsible for the following functions within their divisions—(1) personnel assignments and administration, (2) quantity and quality of the work performed, (3) interpretation of technical directions and institution of appropriate action, (4) preparation of maintenance instructions for work in their

respective technical areas of cognizance, (5) custody, issue, and maintenance of; and the accounting for assigned tools and organizational equipment, (6) establishment of a suitable training program and preparation of suitable lesson plans to be approved by the maintenance officer, (7) safety engineering, and (8) preparation of failure reports.

Functions of Divisions

Planning division, AM-11, screens directives received from the maintenance officer for applicability and forwards copies of them to the appropriate divisions as indicated on the Directives Flow Chart, and initiates requests for material. Some of the other duties of the planning division are to (1) process FUR's, (2) provide stub number information on the maintenance instruction, (3) distribute copies of approved maintenance instruction, (4) plan workload and schedule maintanance work, (5) initiate work orders on scheduled work, (6) maintain the Aircraft Status Board, (7) inform the line maintenance division of action taken to correct discrepancies, (8) prepare work requests to be submitted to and maintain liaison with the supporting activity.

Records and reports division, AM-13, is responsible for maintaining a master log of completed work order and maintenance instructions, and to insure that proper records in proper form are kept by the various divisions as required.

Inspection division, AM-14, establishes inspection procedures and standards to insure that maintenance and repair work on aircraft, engines, accessories and equipage have been performed in accordance with current Navy standards.

Logs and publications division, AM-15, maintains technical publications and a correspondence library and secures applicable classified data. This division also maintains logs, such as aircraft, engine, and others as may be required, in accordance with BuAer instructions and insures the correct disposition of all logs and publications.

Material division, AM-12, is responsible for planning, procuring and expediting material needed to support the workload of the squadron or activity.

The above divisions are staff divisions with the main responsibility of supporting the line divisions.

Avionics division, AM-5, performs maintenance work on the instruments, electronic, and electrical equipment of assigned aircraft. The level of work performed is determined by the class of the maintenance activity.

These are classed as A, B, C, D, E, and F and are as follows:

Class A maintenance (overhaul maintenance) includes conversion, modification, repair, overhaul, emergency manufacture of nonavailable parts requiring heavy installed equipment, and provides technical assistance to the lower levels of maintenance.

Class B maintenance (special maintenance) includes repairs and modification to aircraft and equipment requiring major disassembly, preservation for shipment and storage, emergency manufacture of nonavailable parts requiring installed equipment, and provides technical assistance to lower levels of maintenance. Class B maintenance requires an estimated period of from 91 to 180 days for completion.

Class C maintenance (shop repair maintenance) is performed on parts, subassemblies, assemblies, units, groups, and sets normally located in fixed ship, shore, or mobile shops. It is performed without removal of aircraft or equipment from an operating or flight schedule unless prohibited by insufficient quantities of available spare parts, subassemblies, assemblies, units, groups or sets. Class C maintenance requires an estimated period of from 61 to 90 days for completion.

Class D maintenance (shop maintenance) normally includes preservation, inspection, examination, and specified bench test of parts, subassemblies, assemblies, units, groups and sets removed from aircraft, aircraft equipment, and aircraft support equipment. Correction of discrepancies and compliance with applicable instructions by adjustment, minor repair and/or replacement of equipment is also performed as class D maintenance. Class D maintenance requires an estimated period of from 31 to 60 days for completion.

Class E maintenance (hangar maintenance) is performed at or in a hangar, hangar deck or dock. It is performed during maintenance availabilities, with the

aircraft or equipment removed from the operating or flight schedule. It is performed by all activities assigned operating aircraft or equipment, with authorized and qualified hangar maintenance personnel, using approved and authorized class E maintenance material. Class E maintenance includes all intermediate and specified major, special and preservation inspections. It also includes functional test of aircraft, aircraft equipment and aircraft support equipment systems. Class E maintenance requires an estimated period of from 11 to 30 days for completion.

Class F maintenance (line maintenance) is performed on or in an aircraft or equipment, normally located on a flight line, flight deck, launcher, ramp, or at a buoy, boom, or mast. It is performed during maintenance availabilities, prior to, or between scheduled operations or flight, without removal of the aircraft or equipment from the operating or flight schedule. It is performed by all activities assigned or having physical custody of aircraft or equipment, by authorized and qualified line maintenance personnel, using authorized and approved class F maintenance material. Class F maintenance includes servicing, daily and preflight or preoperation inspections, ground test, and troubleshooting aircraft, aircraft equipment, and aircraft maintenance support equipment systems. Correction of minor discrepancies and compliance with applicable instructions by adjustments and replacement of parts is within the scope of class F maintenance. Class F maintenance requires an estimated period of from 0 to 10 days for completion.

Maintenance Instructions

A maintenance instruction is used at the squadron level for the interpretation and issuance of an order for compliance with directives received from higher authority or to implement local instructions. It is prepared by a division officer designated by the maintenance officer and is then reviewed by the maintenance officer. There are two general classes of work for which maintenance instructions are used:

1. Single Action Maintenance Instruction (SAMI). These are prepared for work of a one-time nature. When

the work ordered is such that it will be completed on an aircraft or piece of equipment by carrying out the instructions set forth, and will not require further action at any time or in any situation on that aircraft or piece of equipment, it is properly called a SAMI. For example, an aircraft service change on all bureau numbers of a certain model aircraft.

2. Continuing Action Maintenance Instruction (CAMI). These are prepared when the work ordered is such that it may recur at intervals on the same aircraft or piece of equipment due to elapsed time or as a result of some situation. For example, an inspection of the landing gear is required whenever a hard or unusual landing has been reported.

A separate serial numbering system is set up for each type of maintenance instruction (SAMI or CAMI) for file control purposes and for cross-reference on work orders. Each supporting work order will merely carry the serial number of the maintenance instruction rather than a repetition of an oftentimes lengthy work description. Detailed instructions for performing the maintenance are to be printed on the back of the form.

Work Orders

Single Action Maintenance Instruction (SAMI's) and Continuing Action Maintenance Instructions (CAMI's) are formal maintenance instructions issued to your maintenance officer from higher authority. These instructions are written in Navy-wide standardized format. To see that these formal instructions and also squadron-originated instructions, are carried out by the shop, work orders are written by the planning division and given to the shop. These work orders have the direct authority of the maintenance officer behind them. Hence, work orders are essentially written commands from the maintenance officer which tell you to perform certain work on certain aircraft at specified times. Often, the manner in which the work is to be done is included.

A good way for you to classify and administer work orders is in accordance with each work order's nature. Since each work order must fall into one of three categories, from your standpoint, you can file them accordingly. These categories are:

1. Special work orders.
2. Standing work orders.
3. Routine work orders.

Special work orders will instruct you to carry out Single Action Maintenance Instructions (SAMI's) when they are received by your maintenance officer from higher authority. They also cover work that is originated in the squadron. In either case, however, special work orders apply only to work of a one-time nature.

Standing work orders will instruct you to carry out Continuing Action Maintenance Instructions (CAMI's) when they are received by your maintenance officer from higher authority. They also cover work originated in the squadron. In either case, however, standing work orders apply only to work that will probably be done more than once, but which cannot be scheduled. This work cannot be scheduled because no one knows when the need for it will arise. For instance, one standing work order states that current limiters will be replaced after being subjected to an overload.

Both special and standing work orders will be serialized by the planning division. Since the serial numbers of the work orders you receive probably will not be in perfect sequence (in-between numbers issued to other divisions) you should assign your own shop serial numbers to all incoming work orders. In this way, with no "gaps" between numbers, all work orders are more easily accounted for.

Routine work orders will instruct you to carry out the routine daily workload, consisting of periodic checks and correction of normal discrepancies. There is no need to serialize routine work orders, since each is turned back in as it is completed. Work done on routine orders will appear in your daily work log along with work done on special and standing orders.

Work Request

The work request is used by a supported activity to request that specific work be performed for it by its supporting activity. The work request originates in the supported squadron for work that is beyond its own capacity to accomplish. The supporting activity reviews the

request and approves or disapproves it. If the request is approved, a work order number is assigned to it and the requesting activity is notified when the work is completed. If the request is disapproved, the reason therefor is entered on the work request and it is returned to the originator.

Status Board

The status board is maintained to provide a visual presentation of current status information on all aircraft in the squadron. The status board (fig. 1-2) is of suitable size and material to indicate such information. Size and location of the board will vary with squadron employment and operating conditions.

MODEL	SQUAD NO.	BUREAU NO.	UP OR DOWN	ENGINE HOURS	HOURS TO INSP.	TYPE INSP.	MONTHS IN SERVICE	DATE LAST INSP.	REMARKS
F8U-1	101	12345	U	44.4	15.6	2nd INT	17	12-1-58	INSTALL ASC 208 NEXT INSP.
F8U-1	102	12356	D	55.5	23.8	ACCEPT	18	11-30-58	

Figure 1-2.—Aircraft status board.

Work Status Report

A work status report is prepared daily by the shop chief, and submitted to the planning division, AM-11. This report indicates the extent of completion in man-hours, of all work orders assigned to the shop. By using status reports, the planning division can develop realistic availability schedules. For instance, if 30 man-hours are required to complete a certain work order, and your status report indicates 25 man-hours have been spent on the work order, then the planning division should be able to safely assume that an additional half-day will be required to complete the work. Status reports should be prepared in duplicate, so that a copy may be retained in your shop. There is no standard format for status reports, because local conditions differ greatly between squadrons (operating practices, size, mission, etc.).

DUTIES OF THE LEADING PETTY OFFICER

Shop Administration

Some of the most important duties that you will be required to perform as a First Class or Chief Aviation Electrician will be in connection with shop administration. As a shop supervisor you will be responsible for the work that is performed in the electric and instrument shop as well as that performed on the line.

There are various aspects of shop administration. Some of the most important of these are discussed.

JOB PRIORITY, SCHEDULING, AND ASSIGNMENTS.—Determining which jobs should be performed first will be one of your major responsibilities. This is an important phase of your work for these decisions determine the use of your facilities—men, material, and machinery. Routine work presents no particular problem to a well organized shop. Rush jobs can cause much confusion unless you have already thought them through and taken steps to see that the work follows well founded principles.

When scheduling work take steps to insure that you will have your men or crews working on different type jobs. If a number of men or crews are assigned to the same type jobs there will be an overdemand for certain test equipment, tools, and work space. This results in confusion and waste of time.

You should include known future assignments in your work schedule. If you know that at a certain date you must perform certain jobs you can rearrange your present work schedule so that routine work will have already been accomplished.

One of the most important aids in supervision is a job plan. When setting up a job plan, consider these questions: (1) What is the job? (2) how can it be accomplished? (3) how many men are required? (4) what tools and materials are necessary? Schedule activities so that work is accomplished in the proper sequence. This is especially important if you have men working on different phases of the same job.

In distributing work, be fair to all the men. It is a natural inclination, and a part of every person's makeup, to give the breaks to the people he likes. The important

thing is to realize that you have this inclination and to control it. Avoid having a man do all the work of one type just because he happens to be an expert in that particular phase of the work. Pass the work around so that each man will get a chance to develop his skill in all phases of an electrician's work. Assign your strikers to assist with various kinds of work so they will get experience on all kinds of jobs.

Rotating assignments makes the work more interesting for the men and, in addition, better qualifies them for advancement in rating. Another good reason for rotating assignments is that if one highly skilled man does all the work of a certain type, you and your shop will be at a great disadvantage should he ever leave the crew. Finally, avoid favoritism; it leads to poor morale and low production. Let ability be the measure of your men. Never give your men reason to believe that the only way to get ahead is to become your pal. Practice the principles of leadership and supervision until they become second nature.

INSPECTION.—The supervisor's function as an inspector is vital to the efficiency and safety of an electric and instrument shop. Frequent and thorough inspections are necessary to attain this twofold objective. On the one hand, check for cleanliness, the proper use of tools and equipment, and strict compliance with all safety precautions; on the other, insist on quality work. By training your men to keep the shop clean and orderly, you are encouraging orderly thought and systematic work habits which will be directly reflected in high quality workmanship. Through inspection you insure that jobs are produced with the most efficient and economical use of equipment and materials, and that work is performed in a safe manner.

TRAINING

The Navy rightly places great emphasis on effective and continuous rate training. As you advance in seniority, it becomes your legal, moral, and practical responsibility to carry out a training program which is the very best of which you are capable.

It is your legal responsibility because your qualifications for advancement in rating clearly demand that you be able to set up and execute an effective training program.

Less explicit, but just as real, are the moral considerations involved. First of all, you are getting paid to do a job. Second, you are in a position of trust because of your greater experience and technical knowledge. For instance, pilots will most readily accept and fly aircraft that you, the senior shop electrician, have worked on. To insure that they have equal confidence in the work of your junior men, they must be convinced that these men can do specific jobs as well as you yourself can. The only way you can obtain such proficiency in your men is to train them thoroughly.

Most important of all, there are practical aspects to the need for an excellent training program. Your squadron's operational readiness depends largely on the ability of its maintenance department. In turn, an important part of the maintenance department's work is done by the Aviation Electricians. Consequently, the quality and scope of your training program has a very real effect on your squadron's effectiveness, and thus on national security. Another practical, though more personal, aspect to consider is that your own job is made easier each time a junior man is taught to do a job without close supervision. Also, when your shop gains the reputation of a "can-do" team, it reflects well on your own prestige.

PLANNING A TRAINING PROGRAM.—The very first phase in developing your training program should be to determine and fix its objectives. On the squadron level, these objectives should be:

1. Training of men on subjects of a general nature as specified by the *Qualifications for Advancement in Rating*. (These appear in this course as appendix III.) This training is intended primarily to aid the men in rate advancement.

2. Training of men on specialized subjects, namely, the circuits and equipment used in the squadron aircraft. This training is intended primarily to improve their daily working proficiency, and thus is generally of more direct benefit to the squadron than rate-advancement training.

The second phase in developing your training program includes a considerable number of steps. The most important of these are:

1. Evaluate each man to be instructed, for the purpose of determining the starting level of the subject matter. For instance, if one or more of your men has never attended a service school, you must commence instruction at the level of fundamental electricity.

2. List the subjects to be taught. The inclusion of a number of the items on this list will be dictated by the *Manual of Qualifications for Advancement in Rating*. These will be general subjects, a very few of which are electron theory, ohm's law, capacitive and inductive characteristics, and fundamental transformer theory. The remainder of the list will be made up of specialized items pertaining only to the particular squadron's aircraft.

3. Search out reference books or publications which cover all the items of the foregoing list. You must thoroughly understand each item yourself. At this same time, the subjects should be arranged in the most logical sequence for teaching.

4. Prepare a lesson plan for each subject. When the lesson plans are completed, they will have to be approved by the maintenance officer, because he is officially responsible for the contents of such training programs.

5. Procure space for carrying out the lecture-type portion of your program. This will usually be in the electric shop. However, if other space is available, you should check such features as possible seating arrangements, ventilation, lighting, and outside noise levels.

TRAINING MATERIALS.—There will be a limited number of items of training materials used in a squadron-level training program. Obviously, it would not be practical to build visual aids such as mock-ups and models, as is done in service schools. Your list of materials for the students probably will include only note pads, pencils, and as many study texts as you can procure from various sources. Your own essential materials will include lesson plans, training records, a blackboard and chalk. The required materials will depend mostly on your individual situation. For instance, if you are in a constantly moving carrier air group unit, your blackboard should be portable, and should fit in a cruise box. For teaching a patrol

squadron crew, the blackboard could be larger and permanently attached to a bulkhead.

TRAINING METHODS.—Training methods cover a large field, which is a course of study in itself. A closer and more detailed study of this field is made in the Manual for Navy Instructors, NavPers 16103-B. Also, the *Military Requirements* training courses, NavPers 10054, 10056, and 10057 contain information on training.

Only the simplest methods of training are mentioned here, but these should be sufficient for informal squadron-level instruction. The first lessons in your training program should deal with electrical fundamentals. These serve to prepare the men for the subsequent teaching of specialized equipment. Fundamentals will be taught mostly by lecturing and using a blackboard to illustrate important points. You should keep in mind during this stage that you are teaching general principles and terms which will be used verbatim when you teach specific circuits later on. That is, you must cover such fundamentals as vacuum tube theory and magnetic amplifiers so thoroughly that no question as to their operating principles will arise when they are later encountered in equipment.

The teaching of fundamentals on the squadron level is more difficult than at service schools, because you probably will not have the means to make demonstrations, or to set up lab problems. Consequently, some parts of the fundamental lessons will have to be carried over into the equipment phases. For instance, it can be stated in the classroom that series motors in general have high starting torques. Later, to demonstrate this point, while operating the specific landing gear circuit used in your squadron's aircraft, you can focus the student's attention on the fact that the landing gear motor (which is a series motor) attains its top speed almost instantaneously each time it is actuated. Thus, the student makes a mental connection between the statement of a general theory, and a factual example of that theory at work. This method of training is very effective.

At its best, classroom instruction is limited in effect. Really useful and practical knowledge is gained by your students when they apply fundamental and theoretical teachings to actual equipment. When you have advanced to the point of commencing instruction on specialized

squadron aircraft equipment, your training methods must be changed somewhat. These changes will involve breaking each lesson into four stages, when teaching equipment. These stages are:

1. Extensive circuit theory and unit function, referencing HMI.

2. Operation and observation of the equipment in action, done by the student at the aircraft, under your supervision.

3. Making calibration or adjustment, done only when such adjustments are actually needed, and under your supervision.

4. Signal tracing, trouble isolation, and parts replacement, done when actually needed, and under your supervision.

Each equipment lesson will deal with only one electrical circuit or set at a time, and as many of the foregoing four steps as possible will be carried out in turn. In most cases only steps 1 and 2 will be carried out as routine instruction. Then, when you receive a discrepancy report on a circuit which has been taught through steps 1 and 2, one or more of your students may accompany you to the aircraft and carry out steps 3 and 4. This method of training is thus seen to serve a dual purpose; it gets your men trained to do a job (the second time without your direct supervision), and also routine maintenance work is accomplished.

TRAINING RECORDS.—From the foregoing, it is apparent that different men may become trained to different levels on different equipment. This is true because some may miss lessons at times. There is also the probability of personnel turnover. Obviously, you must see that a training record is carefully kept on each man, with an entry made each time he has undergone any of the four stages of instruction. A very good form to use is shown in figure 1-3. By using this form, a man's training level for any particular circuit or set may be determined at a glance.

SCHEDULED TRAINING.—It must be assumed from the start that an inflexible training schedule will not work. The extreme variations in routine maintenance workload will not permit a fixed schedule. Therefore, training time must be taken whenever it is available. That is, it is scheduled only to the extent that it will be done if at all

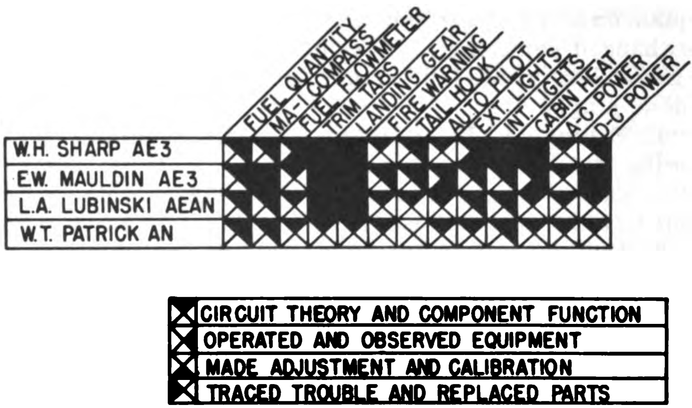


Figure 1-3.—Training chart.

possible some time during the day, but the time will vary. When training is absolutely precluded by a heavy workload, it should be noted in the daily work log. Thus, the time can be made up when the workload is lighter.

NONSCHEDULED TRAINING.—This consists merely of seizing unforeseen opportunities for purposes of training. For instance, a trim-tab actuator lying on a workbench may present the opportunity for you to launch into a discussion of it. This would be an ideal time for you to point out such features as the location of the actuator's throw-limit microswitches, the direction in which to turn the adjustments, where safety wire could be attached, and how the actuator is mounted in the aircraft. Remember, any information you are able to pass to your men, regardless of time, place, or subject matter, is actually a form of training. You should, however, keep careful track of what you have taught, and how thoroughly each subject has been covered.

QUIZ

1. The person who controls personnel assignment within divisions is the
   a. Maintenance Officer
   b. Division Officer
   c. Commanding Officer
   d. Personnel Officer
2. Navy Training Courses are designed to be self-taught because
   a. Navy men are smart enough to understand them
   b. some men depend on them as a source of knowledge in order to advance
   c. it makes it easier to learn
   d. the Navy says they are the best method
3. The responsibility for work that is performed belongs to the
   a. Division Officer
   b. shop supervisor
   c. man who does the work
   d. petty officers in the shop
4. A good rule to remember is to censure privately and praise
   a. at no time
   b. to please a person
   c. in private
   d. in public
5. The person responsible for the preparation of FURS is the
   a. Supply Officer
   b. man who removes the defective part
   c. shop chief
   d. Division Officer
6. A book containing the "do's and don'ts" of leadership is
   a. Military Requirments 3 and 2
   b. Manual of Leadership
   c. Military Requirements 1 and C
   d. How to Lead Men, Volume II
7. Divisions coded AM-11 through AM-15 are
   a. line divisions
   b. staff divisions
   c. maintenance divisions
   d. working divisions
8. Military Requirements 3 and 2 are concerned primarily with knowledge that a petty officer must possess to
   a. pass his second class exams
   b. work independently and assume leadership duties

c. stand shore patrol duty
d. be a master at arms

9. Your attitude toward the chain of command is important because
   a. the men depend on your good attitude
   b. you cannot operate without the chain of command
   c. things couldn't get done otherwise
   d. the whole structure of the Navy depends on ascending and descending responsibilities
10. The upkeep of the A C status board is the responsibility of what division?
    a. Electronics
    b. Logs and publications
    c. Planning
    d. Maintenance
11. Hangar maintenance is classified as
    a. C
    b. D
    c. E
    d. F
12. The manufacture of nonavailable parts is normally done by class
    a. A maintenance
    b. B maintenance
    c. C maintenance
    d. D maintenance
13. Voluntary discipline means that
    a. a person works because he wants to
    b. men work because they are told to
    c. the men work because thev fear punishment
    d. the men discipline themselves when necessary
14. The first phase in developing your training course should be to
    a. select a room
    b. obtain training aids
    c. train in basic things first
    d. determine and fix its objectives
15. A work status report is prepared
    a. daily by the shop chief
    b. weekly by the shop chief
    c. daily by the planning division
    d. weekly by the planning division
16. A SAMI is known as a
    a. single action maintenance instruction
    b. standing work order
    c. work order
    d. service change metal installation

CHAPTER 2

SUPPLY AND PUBLICATIONS

AVIATION SUPPLY

Your Job in Supply

It is important that all naval personnel have a general knowledge of the principles of our present supply system in order to fully and correctly utilize the system. It is of primary importance that administrative and supervisory personnel have a working knowledge of the methods used to obtain and properly account for their particular supplies.

The first part of this chapter outlines your functions with regard to supply and tells you in a general way what you should know and be able to do in fulfilling this part of your job. As a first class or chief, you will probably be either fully or partially in charge of maintenance and operation in your division. You will, therefore, be instrumental in seeing that an adequate supply of spare parts and other materials are available, and also you will help in planning for future needs. These, in general, are your main responsibilities with regard to supply.

A section of chapter 17 in the Navy Training Course, *AE 3 & 2,* NavPers 10348, contains introductory information dealing with aviation supply. Some of the topics covered are—(1) the federal cataloging system, (2) the Federal Stock Catalog, (3) the Aviation Supply Office, and (4) ordering parts and equipment. Most of the information relates to the procedures that should be followed when

preparing requisitions. If you are not familiar with these aspects of aviation supply, it is suggested that you refer to chapter 17 of *AE 3 & 2.*

Aviation Supply Organization

The Bureau of Supplies and Accounts (BuSandA) is the Navy's organization for determining policies and outlining the procedure to be followed in performing supply and fiscal functions both afloat and ashore. Specific and detailed information on Navy supply is contained in the *Bureau of Supplies and Accounts Manual.*

The Aviation Supply Office (ASO) is a joint agency of the Bureau of Supplies and Accounts and the Bureau of Aeronautics, and is charged with the exercise of inventory control for aviation material. It does not stock materials but serves as the control center.

The primary functions of ASO are as follows:

1. Procurement of most aeronautical supplies from manufacturer or other Government departments.
2. Disposal of surplus materials.
3. Distribution, storage, and inventory control of aeronautical materials after procurement.
4. Completion of statistical information to aid in future procurement and distribution of aeronautical materials.
5. Classifying and cataloging of aeronautical materials, and the distribution of such materials.
6. General control and rationing of critical aeronautical materials with the exception of that material controlled directly by BuAer and Fleet Commands.

NOTE: The ASO controls most of the aviation electric and instrument equipment; however, some components, such as electron tubes, are under the control of the Electronics Supply Office (ESO). The trend is to transfer all parts that have common usage throughout the Navy to the ESO.

MATERIAL CONTROL.—The distribution of all aviation material is under the control of some office or bureau of the Navy Department or Fleet Command. That material under the latter control is known as fleet-controlled material and includes those items that are critical due to shortages of supply. Designation of items as fleet-controlled material is made by ASO in the ASO

Monthly Critical List on the basis of recommendations made by the Fleet Commands. Distribution and issuances of fleet-controlled material is made only upon the approval of representatives of the fleet.

The theory behind this system of rationing is that such scarce materials must be used where needed most, and the respective Fleet Commands, being well acquainted with their own operational requirements, are the people most aware of which activity will have the greatest need for each item of critical material.

Distribution of most electrical and instrument items of aeronautical material is under the control of the Bureau of Aeronautics. The nature of the material determines the cognizant agency. Inventory control for the majority of material under the cognizance of BuAer is delegated to ASO.

A partial listing of the control symbols and the cognizant control office or bureau that should be of interest to the Aviation Electrician is as follows:

Cognizance control symbol	Cognizance supply control office or bureau
N	Electronic Supply Office
R	Aviation Supply Office
V	Bureau of Aeronautics
I	Forms and Publications Supply Office

DISTRIBUTION.—To facilitate distribution of aeronautical material, the Aviation Supply Office has established several supply activities. These are:

1. Reserve stock points.
2. Distribution stock points.
3. Primary stock points.
4. Secondary stock points.
5. Satellites.

The function of each of the supply activities is as follows:

RESERVE STOCK POINTS are activities which carry reserve and backup stock for the supply system. These units maintain storehouse facilities for the bulk storage of aeronautical material.

DISTRIBUTION STOCK POINTS are activities carrying stock for the supply support of designated primary and secondary stock points.

PRIMARY STOCK POINTS are units carrying stock for their own consumption and for the supply support of designated activities as secondary stock points, fleet units, yards, district craft, and assigned aircraft. Primary stock points also furnish complete aeronautical supply support to activities designated as satellites.

SECONDARY STOCK POINTS are nonreporting units which carry stock for their own consumption and for the support of assigned aircraft. These activities are shore-based units, continental or extracontinental, which are not classified at a higher level.

SATELLITES are aeronautical activities which are dependent on a primary stock point for complete aeronautical supply support. Such activities will usually be an auxiliary air station, air facilities, and other minor supply activities.

The relationship existing between the various units of the aviation supply system can be understood better by studying the flow chart of aeronautical material shown in figure 2-1.

Federal Cataloging System

The cataloging system developed by the Department of Defense is such that a single listing has been developed that applies to all governmental agencies. This system identifies with one name and number any item of supply that is carried in any or all governmental agencies. In other words, there is one name and stock number for a given item of supply.

A single Federal Stock Catalog, consisting of a number of volumes, sections, and supplements, contains all of the items stocked by the many governmental agencies. The section of this catalog that contains most of the parts that you will order is comprised of Navy Stock Lists.

Navy Stock Lists

To order material and to assure receipt of it by your division, a requisition is completed and submitted to

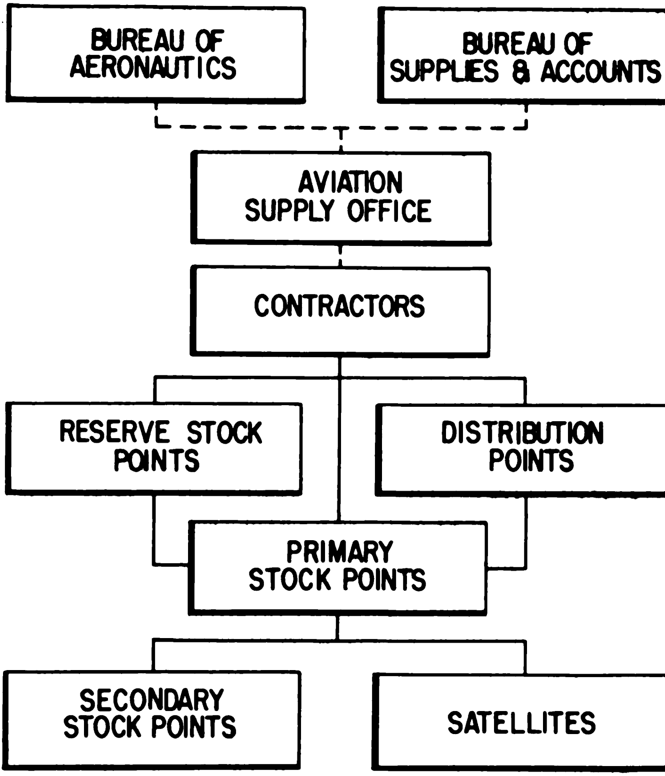


Figure 2-1.—Flow chart of aeronautical material.

Supply. But, to be sure the material is received, more must be done than list on a requisition form the names of the items wanted.

The Navy Stock Lists of the Aviation Supply Office, is the basic stock catalog used by aviation supply personnel. These lists contain the answers to the majority of the material problems in aviation supply; and because of this, a rather complete knowledge of their contents and use will prove of untold value to the electrician.

By spending some of your spare time in becoming familiar with these lists and other supply publications, you will be in a position to expedite parts requisitions when time may be at a premium. A description of these

lists may be found in the Navy Training Course, *Aviation Storekeeper 3 & 2,* NavPers 10398.

Procurement

A high degree of aircraft availability is impossible to maintain unless there is an adequate supply of spare parts and materials. The maintenance spares and parts your activity will be permitted to carry on hand will be governed by the classification given the activity by the Bureau of Aeronautics. The amount of material provided is determined by the BuAer *Initial Outfitting Lists* and *Allowance Lists* (the term allowance lists generally refers to both). These lists are used at the time of initial commissioning or reactivation of a unit. They are lists of equipment and material determined from known or estimated requirements as necessary to place and maintain aeronautical activities in a material readiness condition.

Information relating to ordering material is given in chapter 17 of *AE 3 & 2,* NavPers 10348, and will not be repeated in this chapter.

When ordering allowance lists, be sure to specify clearly the lists desired by section (alphabetical designation), title, effective issue date, and NavAer number. All applicable changes to basic lists will be included with the original lists. In the event the issue requested has been superseded, the latest effective reissue with all applicable changes will be furnished. Allowance lists are reissued periodically. When new issues or reissues are published, they will be listed in the next reissue or supplement of the *Naval Aeronautic Publications Index* (NavAer 00-500).

Allowance lists are divided into sections which pertain to operating equipment, the aircraft, and equipment of the aircraft. Each section is designated by a letter such as B, R, X, or Z. Some sections are issued as individual publications while other sections are issued in a series of publications, each of which pertains to a specific model of equipment or aircraft.

Some of the lists that are of major interest to the Aviation Electrician are as follows:

1. *Airframe and Engine Maintenance Parts,* Section B (NavAer 00-35QB). These are initial outfitting lists that

list peculiar maintenance parts (airframe, engine, accessories) required for the maintenance support of the concerned aircraft.

2. *Shop Handling and Servicing Equipment,* Section G (NavAer 00-35QG). These are allowance lists that list shop, hangar, deck, handling, and servicing equipment required for the maintenance support of aircraft afloat and ashore.

3. *Naval Aeronautic Publications and Forms,* Section K (NavAer 00-35QK).

4. *Standard Hand Tools for Aircraft Maintenance Activities,* Section U (NavAer 00-35QU).

5. Section X (NavAer 00-35QX). These lists concern automatic pilots and compasses.

6. Section Z (NavAer 00-35QZ). These are listings of maintenance parts required for the maintenance support of mobile electric power plants.

Allowance lists can be of much use in identifying supply stock items since they are a listing of material that is consumed but not always stocked by the operating squadron or FASRon. The lists have been made available to squadrons and all fleet activities to be used as a ready reference when ordering from the stocks of the supporting supply activity. Materials represented by these lists are available to Navy squadrons through "Ready-Issue Stores."

Initial Outfitting Lists and *Allowance Lists* should be considered as a necessary instrument in material relations between the shore establishment and the needing unit. The squadron or FASRon electronics officer is directly concerned with lists covering shop and maintenance (operational) equipment in order to determine that all items required for a satisfactory state of material readiness are on hand.

ACCOUNTABILITY SYMBOLS.—The level of accountability for all material is not the same. This level is established by the accountability symbol assigned by the Bureau of Aeronautics. All items received will be identified with a symbol that determines the type of accountability required. The symbol for a particular item may be obtained from allowance lists and also from the stock number data section of the Navy Stock List of the Aviation Supply Office. In allowance lists the symbol is placed in

a column to the right of the listed item; the symbol is stamped on the nameplates of serialized components.

Accountability symbols are useful when—

1. Requisitioning material.
2. Accounting for material that is in use.
3. Disposing of material (turn-in).
4. Processing material for repair or overhaul.
5. Accounting for lost items.

Accountability symbols are as follows:

1. A—Plant property.
2. C—Consumable. These items are considered expendable or consumed in use, and are issued without a turn-in of the replaced item.
3. D—Disposal. These items are technical aviation material and are not issued for replacement purposes without a turn-in of the replaced item.
4. E—Equipage. These items are maintained on a custodial signature basis and will be surveyed when lost or missing.
5. O—Repairable plant property.
6. R—Repairable. These items are not issued for replacement without a turn-in of the replaced item. However, they may be drawn for initial installation without a turn-in.

INVENTORY CONTROL.—Inventory control may be defined as "the formulation and administration of a system of policies and directives concerned with the determination of requirements or excesses and the action necessary to satisfy such requirements or dispose of such excesses." Examples of activities that perform these functions, under overall BuSandA direction, are the Aviation Supply Office (Philadelphia), and the Electronics Supply Office (Great Lakes).

Within the inventory control operation of the shore establishment, Ready-Issue Stores and Shop Stores are for the purpose of getting spare parts and consumables as close to the user as possible and still keep the materials in the accounts of the Navy until they are really needed.

The FASRon's have the responsibility for establishing and operating the ready-issue stores under a Supply Corps officer of the shore activity. The range and quantity of items carried is determined by the supply officer, guided

by usage data, applicable allowance lists, and recommendations submitted by the units supported. A particular effort is made to stock parts and material for which there is the greatest demand, although quantities of items carried normally will not exceed requirements for 60 days.

Shop stores are operated in somewhat the same manner as ready-issue stores except that they are located primarily in industrial or repair activity shop areas, such as in an Overhaul and Repair Department of an air station. Therefore, stock is specialized, stock control and issue are simplified, and the store is operated by personnel who are connected with the shop concerned and familiar with its material requirements.

An inventory is the process of counting and recording the actual quantities of material on hand. Its primary purpose is to bring quantities shown on stock records into balance with actual quantities on hand.

You will be concerned primarily with inventorying aircraft electrical equipment, assemblies, subassemblies, parts, and associated equipment. Whether prescribed locally or by the controlling authority, inventories provide a basis for (1) requisitioning material, (2), accounting for use of material, and (3) disposition of excess material. Controlling activities normally supply inventory forms specifically designed for reporting categories of equipments for which they have cognizance.

SOURCE CODES.—Source codes are codes which indicate to a consumer a source for a part required in the maintenance or repair of an aeronautical article. Specifically, these codes indicate whether the material is to be requisitioned from the supply system; to be manufactured; to be obtained from salvage; not to be replaced since the next higher assembly is to be installed; not to be replaced due to the impracticability of replacement; to be procured for the specific requirement; to use local discretion regarding obtaining a replacement; or failure of the part indicates a requirement for complete overhaul or scrapping of the assembly or equipment.

When ordering a part of an electrical or instrument equipment, always check the source code since this may enable you to prevent much delay in procuring the item. For example, an item may be available only to an overhaul

and repair activity and by knowing this you will not submit an incorrect requisition for that particular item. These codes are listed in the *Illustrated Parts Breakdowns* adjacent to the named part.

Source codes are assigned by BuAer with the assistance and recommendations of the Fleet, ASO, O&R activities, and others. Anticipated or known usage is the primary factor in the assignment of source codes.

It should be noted that bulk materials, standard AN hardware, washers, nuts and bolts, and so forth are not assigned code numbers but are stocked and considered as items of normal inventory stock control.

Source codes that apply to most of the equipment and parts that the Aviation Electrician is required to work with are as follows:

Source code P applies to items which are purchased in view of known or anticipated usage and which are relatively simple to manufacture within the Navy, as necessary.

Source code P1 applies to items which are purchased in view of known or anticipated usage and which are very difficult, impractical, or uneconomical to manufacture within the Navy.

Source code P2 applies to items for which little usage is anticipated but which are purchased in limited quantity for insurance purposes. Items coded P2 are difficult to manufacture, require special tooling and/or stock not normally available within the Naval Establishment, or require long production lead time.

Source code P3 applies to detail items which are purchased in quantity in accordance with the life expectancy of the part. Items coded P3 are deteriorative in nature and may require special storage conditions.

Source code M-F applies to items which are capable of being manufactured within Class C, D, E, or F activities. Items coded M-F have no anticipated or relatively low usage, nor do they possess restrictive installation or storage factors. With respect to support equipment, the manufacturing activity may alter the design, material, and/or processes provided that fit, function, use, and safety are not impaired.

Source code M-O applies to items which are capable of being manufactured within Class A or B activities.

Items coded M-O have no anticipated or relatively low usage, or possess restrictive installation or storage factors.

Source code A-F applies to assemblies which are not purchased but which are to be assembled within Class C, D, E, or F activities prior to installation.

Source code A-O applies to assemblies which are not purchased but which are to be assembled within Class A or B activities prior to installation.

Source code N applies to items which do not meet established criteria for stocking and which are normally readily available from commercial sources. These items are purchased on demand and are for immediate consumption and will not be stock numbered.

A working knowledge of the source coding program will enable you to more efficiently carry out your duties in effecting repair of electrical and instrument equipment with a minimum of delay in waiting for replacement parts. Source coding of aeronautical articles insures a more effective control over manufacturing and procurement, establishes a universal means of obtaining material, and eliminates questions in the electrician's mind as to the proper sources of supply. A description of the source codes is in the front of the *Illustrated Parts Breakdowns*. For detailed information on source codes refer to NavAer 00-53B.

RECORD OF MATERIAL ON ORDER.—A record of the material that you have on order will serve many functions. There will be many instances when there is confusion, loss of time, and misunderstanding in relation to whether or not a certain item has been ordered. Unless a record is kept there will be uncertainty until the item is received or correspondence regarding the order presents some evidence. Records of material ordered will not only enable you to ascertain if it was ordered, but also the priority, date, by whom ordered, and for what unit of equipment. Also, this information will aid in the installation or use of the material, for in many cases the time elapsed may be great and the man doing the work may not be present. The record that has been kept may be used as a reference. A suggested means of keeping such a record is to enter pertinent information on the back of the stub requisition that is retained in the electric shop.

Screening Electrical Equipment

As a first class or chief, it will be your responsibility to determine if an electrical assembly or part should be repaired or turned into Supply for credit or disposition. By utilizing spare equipments, spare parts, tools, and test equipment provided or available, using or servicing activities should exert maximum effort to effect repairs to defective equipment within their own organization.

When it becomes necessary to return material, there are prescribed procedures to be followed. The procedures are somewhat involved and require a great deal of effort but are set forth by the Supply Department of the Navy to facilitate this phase of electrical maintenance. All material that is returned should be identified with a color-coded tag or label. These denote whether the equipment or part is RFI, requires screening, is rejected, is repairable, or is a salvage component. Local instructions will provide you with directions for labeling and tagging your equipment.

Electrical equipment in need of repair or overhaul is returned to Supply as prospective condition code RE or RB material. This identifies the material or equipment that requires screening and/or overhaul prior to being placed in a Ready for Issue (RFI) condition.

Materials returned as excess equipment, that are in proper operating order, will be identified as RFI.

Whenever activities are unable to effect repairs to a unit, assembly, or part which necessitates return to Supply for disposition and the requisitioning of replacement because of the lack of parts, tools, test equipment, or inadequate facilities, a report to that effect shall be made to the Bureau of Aeronautics for analysis and study. This report may be submitted as a comment on the failure report, by official letter, or other means. The information submitted will be used for purposes of planning, correcting deficiencies, and improving field maintenance.

In the event a component or test feature of a specific item of test equipment is defective, and the cognizant activity desires to utilize temporarily the other components of the unit, the complete test equipment may be retained and a requisition submitted to the cognizant supply officer. The requisition shall bear a notation that the

unit is being retained pending receipt of a replacement. For more detailed information about repair of test equipment refer to BuAer Instruction 10550.5A.

Material Reliability Reports

The purpose of the Naval Aeronautical Material Reliability Program is to enable the Bureau of Aeronautics and its contractors to rapidly perform both statistical and technical analyses of equipment failures and to take steps to insure that more reliable equipment is developed. The major aspects of the program are the collecting, compiling, and analyzing of service experience with naval aeronautical materials to determine areas of immediate failures, and trends of impending failures, and to coordinate efforts to correct material deficiencies to improve flight safety, operational utility, and logistic support for operating aircraft.

The Material Reliability Program utilizes two basic forms entitled "Failure, Unsatisfactory, or Removal Report," NavAer 3069, and "Electronic Failure Report," DD 787, for reporting all failures, faults, or malfunctions of aeronautical material. Operating activities are responsible for the prompt submission of failure reports. As a first class or chief, you should insure that the reports submitted from your shop contain an accurate description of the failed item, including the correct stock number, part number, manufacturer, and contract number. Extraordinary efforts should be made to determine precise causes of component failures or malfunctions that are involved in aircraft accidents and FLIGA's (forced landings, incidents, ground accidents). If the determination of the causes of failures or malfunctions in these categories is beyond the capabilities of the reporting custodian and local supporting activities, priority disassembly and inspection reports or laboratory analysis reports, as appropriate, should be requested.

The Navy Training Course *AE 3 & 2,* NavPers 10348, briefly describes the failure reports (FUR & EFR). It presents information as to their purpose, when they should be completed, who should complete them, and where they should be sent. Additional information about these reports will be presented in this chapter; if you are not familiar

with the information contained in the AE 3 & 2 course you should refer to chapter 17 of that course. Detailed information on FUR's and EFR's is contained in NavAer 00.58B.

FAILURE, UNSATISFACTORY, OR REMOVAL REPORT (FUR).—Figure 2-2 illustrates a FUR report. Refer to this figure when studying the description of the material that is to be placed in each space.

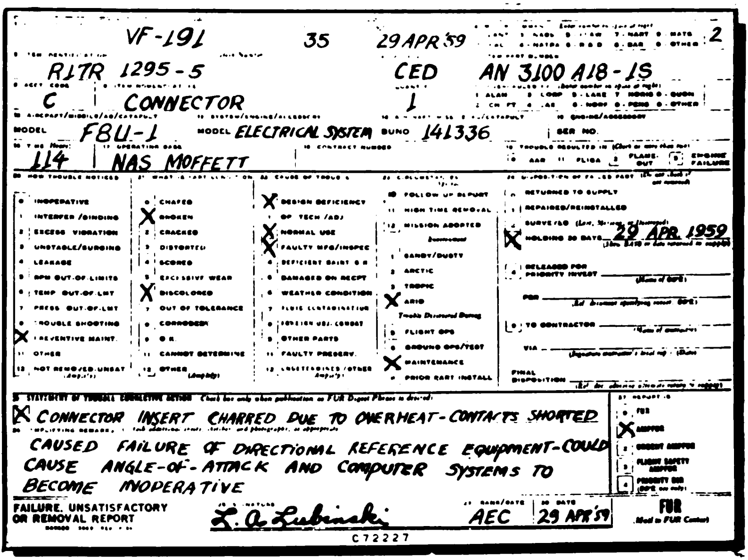


Figure 2-2.—FUR (NavAer 3069, Rev. 8-56.)

Space 1. REPORTING ACTIVITY. Insert authorized activity designation, (VP-791, NAS Memphis, etc.)

Space 2. REPORT SERIAL. Each reporting activity will assign serial numbers to reports, starting with serial 1 at the beginning of each calendar year and progressing through serial 999. When reports from any activity exceed 999, then the serial will recommence with serial 1.

Space 3. DATE OF TROUBLE. Insert date fault or failure was actually encountered or found.

Space 4. MAJOR COMMAND. Insert appropriate number in space at right.

Space 5. ITEM IDENTIFICATION. Insert correct stock number as obtained from catalogs or handbooks.

Space 6. MANUFACTURER'S CODE. Insert the correct code for the contractor or manufacturer of the deficient part. Correct codes may be obtained from the nameplates of the part or assembly, from the IPB, or from section 0003 of the *ASO Catalog*.

Space 7. ITEM PART NUMBER. Insert the manufacturer's part number as obtained from the nameplate or otherwise appearing on the failed part. If no part number is affixed, leave this space blank.

Space 8. ACCOUNTABILITY CODE. Insert proper material accountability code as appropriate.

Space 9. ITEM NOMENCLATURE. Insert noun name of part or assembly in which failure occurred (actuator, starter, etc.).

Space 10. QUANTITY. Insert quantity of the deficient part replaced on a specific aircraft, or received from supply.

Space 11. OVERHAULED BY. Insert the appropriate overhaul activity code number in the space to the right. Overhaul activity may be determined from the decal or stamp on the part itself, or from logbook or accessory record cards. This space must be completed when item is known to have been overhauled. Do NOT complete if item has not been overhauled.

Space 12. AIRCRAFT/MISSILE/ARRESTING GEAR/CATAPULT MODEL. Insert the correct model such as F11F-2, AAM-N2, Mark 7, Mod 0, etc., in which the failure or malfunction occurred.

Space 13. SYSTEM/ENGINE/ACCESSORY MODEL. Complete this entry as follows:

(a) When an engine part is at fault, enter the complete engine model in this space, (J48-P8, R3350-30W, etc.).

(b) When an engine accessory is faulty, enter the accessory model in this space, (A7011E (fuel control), 2CM7703 (starter generator), etc.).

(c) When discrepancy cannot be determined to be either of the above, enter the system at fault in this space (electrical system, hydraulic system, etc.).

Space 14. AIRCRAFT/MISSILE/ARRESTING GEAR/CATAPULT BUREAU NUMBER. Insert the bureau number or the bureau assigned serial number in which the deficiency occurred. Do NOT enter locally assigned numbers.

Space 15. ENGINE/ACCESSORY SERIAL NUMBER. Enter the serial number from the nameplate on the item in which failure or malfunction occurred. If accessory is noted in space 13, enter accessory serial number.

Space 16. TIME. Insert the time the failed or faulty item had been in service prior to failure, since new or overhauled. Reported time in service should be obtained from the applicable logbook or accessory record card. When this information is not available, a reasonably accurate estimate of time in service should be given based on aircraft or engine time and considering usage of the reported part in relation to aircraft or engine usage. If report concerns unsatisfactory material received from the supply system, enter RFI. THIS ENTRY MUST BE COMPLETED ON ALL REPORTS.

Space 17. OPERATING BASE. Insert the name or location of the base or ship from which the aircraft, missile, arresting gear, or catapult is operated at the time the failure occurred.

Space 18. CONTRACT NUMBER. Enter the contract number of the part or assembly in which failure occurred. This number may be obtained from the nameplate of the part or assembly, logbooks or accessory record cards, shipping boxes or cases, or shipping documents.

Space 19. TROUBLE RESULTED IN. Requires AMPFUR. Check one or two of the check boxes as applicable. Do not check more than two. When AAR or FLIGA is checked, enter applicable AAR or FLIGA serial number in space 26 (Amplifying Remarks).

Space 20. HOW TROUBLE NOTICED. Check box best describing general indication of how the trouble was first noticed. Do not check more than one box. NOTE: If box eleven (11) or twelve (12) is checked, it is necessary that the report be designated an AMPFUR.

Space 21. WHAT IS PART CONDITION? Check box which most appropriately describes the condition of the part failed or removed. Do not check more than one box. NOTE: If box eleven (11) or twelve (12) is checked, it is necessary that the report be designated an AMPFUR.

Space 22. CAUSE OF TROUBLE. Check box which most appropriately describes the suspected cause for the reported failure or removal. NOTE: When box twelve (12) is checked, the report must be designated an AMPFUR.

Space 23. CIRCUMSTANCES. Check no more than one box in each group under this heading appropriate to the reported discrepancy.

Space 24. DISPOSITION OF FAILED MATERIAL. Check one box to describe the action taken to account for the removed or failed part. Special instructions for this entry are as follows:

(a) When box 3, 4, or 5 is checked, the report must be designated an AMPFUR.

(b) When box 3 is checked, the entry "Show BASO or date returned to Supply" will be completed on the file copy only, to complete the reporting activity's material accountability records.

(c) When box 4 is checked, complete both entries. If the part is released for O&R investigation by local arrangement due to proximity of a qualified Overhaul and Repair Department, and coordination with the cognizant BAMR has not been required, note the governing work request identification and date in the entry entitled "Ref. Document specifying investigating O&R." In all other cases, note the appropriate BAMR reference identification and date designating the Overhaul and Repair Department to perform the priority investigation.

(d) When box 5 is checked, note the name of the contractor to whom the material is being released and obtain the signature of the contractor's authorized representative on the FUR and file copies before submitting the report.

(e) The entry "Final Disposition" at the bottom of space 24 will be completed on the file copy only whenever box 4 or 5 is checked. To complete the reporting activity's material accountability, this entry should show the identification and date of the document advising the disposition of released material upon completion of the investigation.

Space 25. STATEMENT OF TROUBLE. Not required on FUR's.

Space 26. AMPLIFYING REMARKS. Not required on FUR's.

Space 27. REPORT IS. Check appropriate box. Under no circumstances shall a report containing entries in space 25 or 26 be submitted as a FUR.

Space 28. SIGNATURE. This space will contain the signature of the qualified person designated to review and approve the report.

Space 29. RANK/RATE. Insert appropriate rank or rate of the person approving the report.

Space 30. DATE. Enter the date the report is mailed.

When the failure report is submitted as an AMPFUR it shall contain the following additional information:

1. STATEMENT OF TROUBLE (space 25). A brief concise statement of the difficulty experienced and whatever corrective action was taken; for example, "Generator voltage fluctuates at high altitude due to rapid brush wear—Replaced brushes." The statement will be reviewed for publication in the tabulated section of the Reliability Digest only when the box to the left of this space is checked. Publication of the statement will be determined on the basis of general interest in the problem by all custodians of the aircraft or equipment in which the trouble was located.

2. AMPLIFYING REMARKS (space 26). Enter all available information concerning the circumstances of the failure or malfunction.

When priority investigation or corrective action is required, the report is designated as an URGENT or FLIGHT SAFETY AMPFUR, by checking box 2 or 3 in space 27. The election of a priority category will at times be directed by BuAer, by major commands, or by local commanders. In other cases, the election of a priority report will be the result of the reporting activity's operational needs or of a flight safety occurrence. The first known instance of a failure or malfunction need not result in priority report submission. In such instances, however, an URGENT AMPFUR may be submitted and the material retained for 30 days. The following criteria are suggested for priority report submission:

1. URGENT AMPFUR

a. Flight safety is not involved.

b. Aircraft availability is seriously impaired for assigned mission as a result of a particular material deficiency.

c. Major material deficiencies are experienced on newly assigned aircraft, or on new production aircraft.

d. No indication of corrective action being taken on previously reported failures or malfunctions in which excessive maintenance time is required. Activities should insure such problems have not been reviewed in the Reliability Digest prior to report submission.

e. Unusual occurrences of material failures for which the cause cannot be determined.

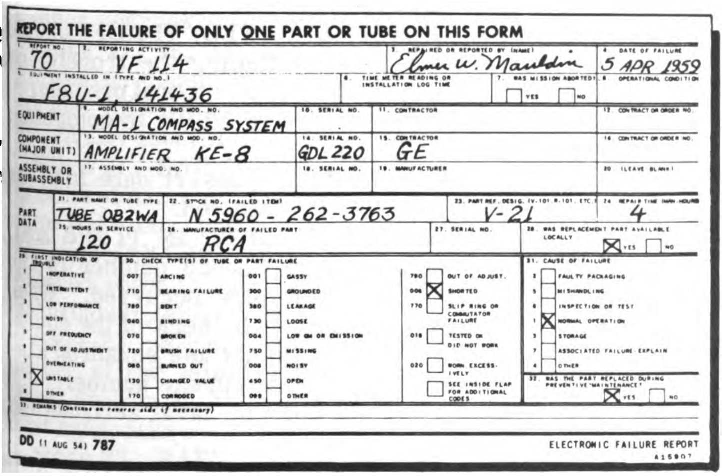
2. FLIGHT SAFETY AMPFUR

a. Failure or malfunction is the primary cause of an aircraft accident, forced landing, or incident.

b. The primary cause of an accident or incident is undetermined, but a material deficiency was involved.

c. Any other occurrence involving material deficiencies which in the opinion of the commanding officer involves flight safety.

ELECTRONIC FAILURE REPORT (EFR).—Figure 2-3 illustrates an EFR. EFR's are submitted for all failures or unsatisfactory conditions of electron tubes and electronic or electrical parts, sets, or systems. A report must be submitted for each failure that occurs, or upon determining that a part or tube is defective or unsatisfactory for any reason. In cases where two or more associated parts are found to be defective, and doubt exists as to which part is primarily at fault, each suspected part must be reported separately. Each report must


REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1. REPORT NO. 70
2. REPORTING ACTIVITY VF 114
3. REPAIRED OR REPORTED BY (NAME) Elmer W. Mauldin
4. DATE OF FAILURE 5 APR 1959
5. EQUIPMENT INSTALLED IN (TYPE AND NO.) F8U-1, 141436
6. TIME METER READING OR INSTALLATION LOG TIME
7. WAS MISSION ABORTED? YES NO
8. OPERATIONAL CONDITION

EQUIPMENT
9. MODEL DESIGNATION AND MOD. NO. MA-1 COMPASS SYSTEM
10. SERIAL NO.
11. CONTRACTOR
12. CONTRACT OR ORDER NO.

COMPONENT (MAJOR UNIT)
13. MODEL DESIGNATION AND MOD. NO. AMPLIFIER KE-8
14. SERIAL NO. GDL 220
15. CONTRACTOR GE
16. CONTRACT OR ORDER NO.

ASSEMBLY OR SUBASSEMBLY
17. ASSEMBLY AND MOD. NO.
18. SERIAL NO.
19. MANUFACTURER
20. (LEAVE BLANK)

PART DATA
21. PART NAME OR TUBE TYPE TUBE OB2WA
22. STOCK NO. (FAILED ITEM) N 5960 - 262-3763
23. PART REF. DESIG. (V-101, R-101, ETC.) V-21
24. REPAIR TIME (MAN-HOURS) 4
25. HOURS IN SERVICE 120
26. MANUFACTURER OF FAILED PART RCA
27. SERIAL NO.
28. WAS REPLACEMENT PART AVAILABLE LOCALLY [X] YES [ ] NO

29. FIRST INDICATION OF TROUBLE
1 INOPERATIVE
2 INTERMITTENT
3 LOW PERFORMANCE
4 NOISY
5 OFF FREQUENCY
6 OUT OF ADJUSTMENT
7 OVERHEATING
8 [X] UNSTABLE
9 OTHER

30. CHECK TYPE(S) OF TUBE OR PART FAILURE
007 ARCING
710 BEARING FAILURE
780 BENT
040 BINDING
070 BROKEN
720 BRUSH FAILURE
080 BURNED OUT
130 CHANGED VALUE
170 CORRODED
001 GASSY
300 GROUNDED
380 LEAKAGE
730 LOOSE
004 LOW GM OR EMISSION
750 MISSING
008 NOISY
450 OPEN
099 OTHER
790 OUT OF ADJUST.
006 [X] SHORTED
770 SLIP RING OR COMMUTATOR FAILURE
018 TESTED OK DID NOT WORK
020 WORN EXCESSIVELY
SEE INSIDE FLAP FOR ADDITIONAL CODES

31. CAUSE OF FAILURE
2 FAULTY PACKAGING
5 MISHANDLING
6 INSPECTION OR TEST
1 [X] NORMAL OPERATION
3 STORAGE
7 ASSOCIATED FAILURE-EXPLAIN
4 OTHER

32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? [X] YES [ ] NO

33. REMARKS (Continue on reverse side if necessary)

DD (1 AUG 54) 787

ELECTRONIC FAILURE REPORT

A15907

Figure 2-3.—EFR (DD 787).

refer to all other reports of the associated failure. All reports of a multiple failure of the associated parts should then be fastened together to permit rapid evaluation. EFR's and FUR's should be submitted daily. Those reports that include amplifying remarks and photographic enclosures may be delayed for as many as three days.

When preparing an EFR, it is necessary that you make all required entries to insure maximum benefit from the system. The entries on this form should be completed as follows (refer to fig. 2-3):

Space 1. REPORT NUMBER. Each reporting activity will assign serial numbers to reports, starting with number 1 at the beginning of each calendar year and progressing through number 999. When reports from an activity exceeds 999, the serials recommence with number 1. This cycling will be repeated as often as necessary during the calendar year. Do not use a calendar year suffix with this serial.

Space 2. REPORTING ACTIVITY. Enter the name of the activity originating the report. Normally, this is the activity performing the maintenance, or the custodian of the item at the time of reporting. Abbreviated administrative titles without prefixes shall be used, such as VP-791, VX-1, NAS Memphis, and so forth. Squadron detachments or units should use the parent squadron number and the detachment number or letter.

Space 3. REPAIRED OR REPORTED. The EFR should be signed by the person actually finding the trouble, or performing the maintenance or repair. Local procedures will be established for the review of EFR's by competent authority prior to submission.

Space 4. DATE OF FAILURE. Insert date fault or failure was actually reported or detected.

Space 5. EQUIPMENT INSTALLED IN (TYPE AND NO.). Insert the model and the bureau number of the aircraft in which the fault or failure occurred. When fault or failure is found during bench check of the equipment, insert the word BENCH. Do not use squadron aircraft numbers in lieu of the official bureau number.

Spaces 6, 7, and 8 are not used by naval aeronautical activities.

Space 9. (EQUIPMENT) MODEL DESIGNATION AND MOD NUMBER. Insert the recognized designation of the

system or set in which the failure occurred, such as G-3 autopilot, MA-1 compass, and so forth.

Space 10. SERIAL NUMBER. This space will be used only when the set is a self-contained unit. When the failure occurs in a unit of a set, space 14 will be used.

Space 11. CONTRACTOR. When the equipment noted in space 9 is a self-contained unit, enter the proper code for the manufacturer.

Space 12. CONTRACT NUMBER. Complete only when the equipment in space 9 is a self-contained unit.

Space 13. (COMPONENT) MODEL DESIGNATION AND MOD NUMBER. This entry is the one most commonly used in failure studies and will be used in preference to space 9 when the failure occurs in any unit of an equipment.

Space 14. SERIAL NUMBER. Enter the serial number of the unit (black box) in which failed part is located. This is obtained from the nameplate.

Space 15. CONTRACTOR. Enter the code letters for the manufacturer of the unit in which failed part is located. This code is usually on the nameplate or in applicable handbooks.

Space 16. CONTRACT NUMBER. Enter the contract, or order number for the unit in which failure occurred, when such information is available from the nameplate or other sources.

Space 17, 18, 19, and 20. Use only when applicable. Information required is similar to that required for a unit and will be furnished only when a subassembly is specifically identified by these entries.

Space 21. PART NAME OR TUBE TYPE. Enter the recognized name of the failed part (capacitor, resistor, motor, tube, etc.) and the tube type for tube failures (tube 5654, tube 6X4-W, etc.). If a complete subassembly is replaced, enter the type, such as channel amplifier, pitch synchronizer, and so forth.

Space 22. STOCK NUMBER. Enter correct stock number of the failed part as obtained from Navy Stock Lists, Section R Allowance Lists, or applicable equipment handbooks.

Space 23. PART REF. DESIGNATOR. Enter the part reference designator (symbol number) of the failed part, such as B-101, C-101, R-304, V-209, and so forth, as

determined from the circuit diagram of the handbook for the particular equipment.

Space 24. REPAIR TIME. Enter the actual time required to isolate and repair the trouble reported. This time should be noted for the isolation and replacement of a single part. Where several parts contribute to an equipment failure and separate reports are submitted, the time for replacing each item should be calculated separately.

Space 25. HOURS IN SERVICE. Enter the best available operating time on the item since new or overhauled. If time meters are not installed and no maintenance records are available, enter a reasonably accurate estimate of time in service. THIS ENTRY MUST BE COMPLETED ON EACH EFR.

Space 26. MANUFACTURER OF FAILED PART. When available, enter the code for the manufacturer of the failed part. Reports concerning electron tubes should always contain this entry. Correct codes are contained in the *Aviation Supply Office Catalog*, section 0003.

Space 27. SERIAL NUMBER. This space should be completed only when the failed part contains a serial number.

Space 28. WAS REPLACEMENT PART AVAILABLE LOCALLY? Check YES if replacement part was available in shop stores or in local supply stocks, otherwise check NO.

Space 29. FIRST INDICATION OF TROUBLE. Check the one box which most appropriately describes the first indication of a fault or failure.

Space 30. CHECK TYPE OF PART FAILURE. Check the one box which most appropriately describes the real or suspected condition of the part replaced.

Space 31. CAUSE OF FAILURE. Check the one box most descriptive of the cause for the part failing.

Space 32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? Check as appropriate.

Space 33. REMARKS. Enter all historical or engineering comments when available and when a failure warrants it. Comments may be continued on the reverse of the form or on separate sheets of bond paper and attached to the report. Photographs (8 x 10 inch, glossy finish), drawings, or sketches should be attached to the

EFR when such matter will assist in determining the areas or causes of failure.

Maintenance Usage Data

Maintenance usage data give percentages of replacement relative to hours of aircraft and equipment operation. These percentages of replacement are applied to operational plans to determine probable future usage. Usage data are used in connection with the PURS (Program Usage Replenishment System) Program and as such it is the important part of that program because it furnishes data from the field and fleet. Usage data determine the quantities of materials that will be placed on allowance lists. With that in mind, you can easily see the importance of the information that they contain. The lack of accurate and timely usage information can cause material shortages. Only a well-organized and smoothly functioning Usage Data Program can show realistic material needs, and reduce to a minimum the element of guess work in the determination of material requirements.

Maintenance Usage Data Report forms are provided for the use of activities reporting usage data. The cover page of the form indicates the model aircraft or the type of avionic equipment for which usage data are being collected. Operating maintenance activities designated by the cognizant command use these forms as a usage report. Ultimate consumer activities such as carriers, tenders, FASRons, self-supporting aircraft squadrons, other designated squadrons, battleships, cruisers, Reserve Air Stations, FAETU's, Air Reserve Training Units, and Marine Service Squadrons will be designated to submit usage reports. The reports are submitted monthly to the Aviation Supply Office. On the activity level, they are submitted by the Maintenance and/or Electronics Officer and approved by the commanding officer.

The report forms consist of a cover page, instruction page, operational data and "remarks" page, usage section, and "write-in" page. These forms are distributed directly by ASO to the activities designated to submit usage data. Usage occurring on items not appearing in the form will be legibly "written-in" on the blank page

provided. To be of value to ASO, utmost care should be exercised in fully identifying the "write-in" items reported. "Write-in" items must show the stock number (or manufacturer part number), brief nomenclature, unit of issue, and quantity used. For avionic "write-in" items, identify the usage by part number, reference symbol, and major assembly.

Usage data are important and entail a great deal of work. An accounting of materials used must be made, so learn what should be done and how to do it. The big problem is not in filling out the necessary forms but it is one of keeping correct and up-to-date records of the materials that have been used. With proper records you should experience little trouble in fulfilling this administrative responsibility of your rate.

Aircraft Inventory Logs and Records

An aircraft inventory log or inventory record is used to facilitate the transfer of naval aircraft between activities giving assurance that the aircraft and its equipment are intact. No aircraft will be transferred or accepted without an inventory log or record. A log or record, as the case may be, is provided for each aircraft and is generally kept by the log section of the maintenance department. Presently, both type reports (log or record) are used by the Navy; however, all new aircraft are provided with the record type report.

The *Standard Inventory Log* is an official BuAer publication bearing a NavAer designation applicable to each specific aircraft model. The *Aircraft Inventory Record* is a Department of Defense publication, and those prepared for the Navy do not bear a NavAer designation.

The log is subdivided into groups of equipment (e.g. instrument and navigation, armament, and electronic). The components thereof are listed in alphabetical sequence and according to their location in the aircraft, with the exception of the electronic equipment, in which case all units of an equipment are listed in one place regardless of their location in the aircraft. Stock numbers are also supplied for individual items, and are used for ready reference when replacements are required.

The record includes a sectional breakdown diagram of the applicable aircraft. This diagram consists of a side elevation and/or the plan view of a wing, or in the case of twin-boomed or flying wing aircraft, the perspective view. To facilitate inventorying, the sections of the diagram are identified by letters, the letter A being assigned to the foremost section, B to the next, and so on, generally to the rear of the aircraft. The letter R, as part of the item number, denotes items mounted on the exterior of the fuselage, and the letter F denotes items to which access is gained from the fuselage. Subdivisions of sections may be identified by a lower-case letter such as Aa, Ac, and so forth. The equipment list portion of the record is divided into sections, each of which lists the items pertaining to a particular section of the aircraft, as indicated on the sectional breakdown diagram. Within each section, individual items are numbered as nearly as possible in the sequence of their physical location in the aircraft without regard to their relation to specific equipment. Stock numbers are not supplied as part of the equipment listing in Inventory Records.

Standard Inventory Logs are prepared and distributed by the Aviation Supply Office, and are kept as up-to-date as possible. Logs are distributed at the time of acceptance of each new aircraft. Reissues and revisions are distributed direct to the reporting custodians.

The *Aircraft Inventory Record* is prepared by the applicable aircraft manufacturer, and delivered with each individual aircraft. They are kept up-to-date by the activity to which the aircraft is assigned.

Upon transfer of an aircraft, representatives from the transferring and receiving activities will jointly inventory and record, in the appropriate column provided, the quantity of each item which is ascertained to be on board the aircraft at the time of transfer. In the case of missing items, the transferring activity will make every effort to locate the missing items or to withdraw from store the replacement items necessary to complete the inventory. If it is impossible to locate or supply the missing items, the notation "Missing items are not available" shall be placed on the *Report of Inventory Form* in the *Standard Inventory Log* or the *Shortages Form* in the *Aircraft Inventory Record*. An explanatory statement signed by the

transferring representative shall be placed with this form, indicating the authority for these shortages. On the basis of this statement, the receiving activity will fill the shortages from stock and account for them in the normal manner.

When an aircraft is stricken (disposed of), the *Standard Aircraft Inventory Log or Aircraft Inventory Record* will normally be destroyed at the time of disposal of the aircraft. In the event that an aircraft is being transferred to other agencies, private concerns, or other Governments, and so forth, the inventory log or the record will be transferred with the aircraft as security regulations permit. On occasions when an accident causes strike of the aircraft, the inventory log or the record will be retained by the striking or salvaging activity as long as required by authorities conducting the investigation, and then destroyed.

Survey of Material

When property must be reevaluated or expended from the records due to loss, damage, deterioration, or normal wear a survey must be made to obtain proper authority to write this material off the books. The survey request provides a record showing the cause, condition, responsibility, recommendation for disposition, and authority to expend material from the records. Think of a survey as being an administrative examination into the cause of material being lost to use. Figure 2-4 shows the standard survey form that is used when a survey is made.

A survey may be either informal or formal, depending on the circumstances.

A formal survey is required for those classes of materials or articles so designated by the bureau or office concerned, or when specifically directed by the commanding officer. A formal survey is made by either a commissioned officer or a board of three officers. At least one of the board officers must be commissioned. The commanding officer appoints those who serve on the survey. Neither the commanding officer, the officer on whose records the material being surveyed is carried, nor the officer charged with the custody of the material being surveyed, may serve on a survey board.

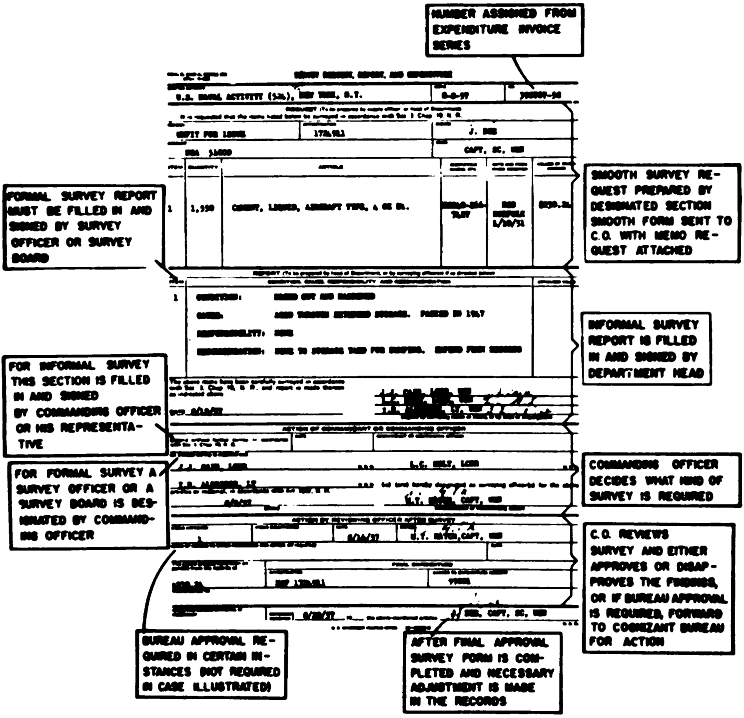


Figure 2-4.—Survey Request, Report, and Expenditure (S. and A. Form 154).

An informal survey is made by the head of the department having custody of the material to be surveyed. Informal surveys are used in all cases when a formal survey is not required or directed by the commanding officer.

PREPARATION OF REQUEST FOR SURVEY.—You will not have the responsibility of preparing final survey forms; however, as a first class or chief, you are apt to be required to provide your division officer with certain information when he is making a survey. Because of this, you should be familiar with the general procedures that are followed.

A request for survey may be originated by a department, division, or section head or a designated subordinate as prescribed by local regulations. Normally, requests for survey are originated in the department

having custody of the material being surveyed. The initial survey request is made on a rough copy of S. and A. Form 154. A statement by the originator is placed on or attached to the request for survey relative to the condition of material; cause of condition surrounding the loss, damage, deterioration, or obsolescence of material; responsibility for cause or condition of material or reason why responsibility cannot be determined; and recommended disposition of material or action to be taken.

Upon receipt of the rough copy, the designated group or section prepares a sufficient number of smooth copies of the request for distribution in accordance with local regulations. The smooth survey request is filled out down to the caption "Report." It is then forwarded to the commanding officer who will determine whether the survey will be formal or informal. If formal, the survey request is forwarded to the designated surveying officer(s); if informal, it is forwarded to the head of a department for survey action.

The statement by the originator as to cause, condition, and so forth, is attached to the smooth request for survey for evaluation by the surveying officer(s). After the survey has been completed by the head of a department or surveying officer(s), it is returned to the commanding officer for review and action. After approval by the commanding officer, the survey request is forwarded to the cognizant Fleet Command and/or Bureau for final review and approval when so required.

PUBLICATIONS

As a first class or chief, your responsibilities in connection with installation, adjusting, maintaining, and testing electrical and instrument equipment will be much greater than they were when you were a lower rated petty officer. You will be required to have quick and accurate answers to many questions. Since there is a wide variety of this complex equipment, you cannot expect to have a ready answer to all questions. However, you can become familiar with the published materials that contain the answers and by so doing will be able to take positive action. Some of the publications that should prove most helpful will be discussed.

Chapter 17 of the training course *AE 3 & 2,* NavPers 10348, contains a section on publications. The material is written primarily for the AE striker and the AE3. Coverage is given to various handbook publications issued by BuAer (HMI, HOI, HSI, IPB); general letter publications (BuAer Instructions and Notices, TO's and TN's); specific letter publications (Changes or Bulletins); the *Naval Aeronautic Publications Index;* and the Navy Directives System (Instructions and Notices). This information will not be repeated in this chapter.

Specifications and Standards

Specifications are written to insure that the products manufactured for the Navy meet certain requirements. They are written primarily for the manufacturer; however, the information that they contain can be of much use at the operating or squadron level.

Specifications are clear and accurate descriptions of technical requirements for a material, a product, or service. They include the procedure for determining that the requirements have been met. Specifications do not remain static after issue but are amended or revised as conditions and requirements change. Those that are written for use by the Military Departments will be issued in either the federal or military series. They are printed in a standard size, 8 by 10-1/2 inches. Only the military series will be described since most of the specifications that can be of use to you will be of this type.

MILITARY SPECIFICATIONS.—Military specifications (formerly known as Joint Army-Navy specifications) cover materials, products, or services used only or predominantly by military activities. These specifications were issued first under the auspices of the Joint Army-Navy Specifications Board as JAN specifications. As existing JAN specifications are revised, the prefixes are changed to MIL although the number remains the same.

Military specifications are identified by a symbol composed of three parts. These parts are the letters MIL followed by a single letter, which is the first letter of the first word in the title, and a nonsignificant serial number. Most of the specifications that can be of help to you are prepared by or under the direction of BuAer.

These are intended for use particularly in applications to naval aircraft, and as such will be the ones that should be available at your activity.

The publication *List of Military Specifications and Standards used by the Bureau of Aeronautics*, NA 00-25-544, is a complete listing of the military specifications and standards used by the Bureau of Aeronautics. These specifications may be used as an aid in the performance of a particular installation or test; they also provide an excellent source of information of a general nature.

Examples of information that may be obtained from military specifications listed in this publication is as follows:

MIL-C-7834, *Compass Swinging, Aircraft*

MIL-E-7894A(ASG), *Electric Power, Aircraft, Characteristics of*

MIL-B-5087A(ASG), *Bonding, Electrical (For Aircraft)*

MIL-W-5088B(ASG), *Wiring, Aircraft, Installation of*

MILITARY STANDARDS.—These include engineering practices, charts, categories of dimensional and functional details, graphs, formulas, and lists. They are normally issued in book form, but may be in unit page form when the standard requires only one sheet. These standards are identified by the symbol MIL-STD followed by a hyphen and Arabic numerals assigned to the standard. An example of a military standard is as follows:

MIL-STD-15A, *Electrical and Electronic Symbols*

The purpose of this standard is to establish a uniform system of symbols for use on drawings of electric and electronic circuits. It establishes principles governing the formation and application of electrical and electronic symbols. Also, it provides a list of such symbols for electrical and electronic parts and assemblies or subassemblies shown on diagrams (wiring, schematic, etc.).

An index of military standards is contained in the publication *Military Specifications and Standards, NA 00-25-544.*

Aircraft Instruments and Accessories Bulletins

These bulletins are issued in order that information and changes pertaining to various instruments and accessories may be more readily distributed and made available

to the units concerned. They are prepared, issued, and distributed by the Bureau of Aeronautics at irregular intervals, and are numbered consecutively for each year.

The format of both the instruments and accessories bulletins is basically the same. A typical bulletin presents information under the following headings:

Subject:
Publications Affected.
Application.
Compliance.
Detailed Instructions.
Parts Required.
Parts Removed.
Special Tools Required.
Source of Parts.
Man-Hours Required.
Disposition of Parts Removed.
Effect on Weight and Balance.

Many times the nature of the information being presented is such that every major heading need not be utilized. When this is the case, words such as "none," "not applicable," and so forth are inserted.

These bulletins can be of much use in presenting new information. An up-to-date file should be maintained and it should be kept in an easily accessible place.

The *Naval Aeronautic Publications Index*, NavAer 00-500, contains a listing of all current instruments and accessoreis bulletins. Consult the general alphabetical index, located in the back of the index, for page number references for the listings of the bulletins.

Type Command Bulletins and Instructions

The final operational control of naval aviation rests with the Fleet and Task Force commanders. Yet, in a sense, the Commanders Naval Air Force U. S. Pacific Fleet and Atlantic Fleet direct naval aviation. They establish policies regarding the organization, maintenance, and employment of fleet aviation; study the strategic situation and make recommendations concerning the distribution of naval air forces; and advise the Fleet commanders on air operations. Type commanders (COMNAVAIRPAC and COMNAVAIRLANT) are responsible for

overhaul and maintenance of aircraft and supplies, for squadron training, and for the preparation of operational doctrines for all types of aircraft. In performing these functions COMNAVAIRPAC and COMNAVAIRLANT maintain close liaison with DCNO (AIR) and the Bureau of Aeronautics.

Type commanders issue technical publications, usually in letter or directive form, that contain information for maintenance personnel. Bulletin type releases are usually used in promulgating this information. As of June 1957, COMNAVAIRPAC information was released in one of the following types of bulletins:

Category	
General Aircraft Bulletin	GAB
Model Aircraft Bulletin	AB
General Engine Bulletin	GEB
Model Engine Bulletin	EB
Special Weapons Bulletin	SWB
General Avionics Bulletin	GAVB
Aircraft Model Avionics Bulletin	AVB
Catapult and Arresting Gear Bulletin	CAGB
General Support Equipment Bulletin	GSEB

Bulletins are numbered consecutively for one-year periods and include the calendar year. A bulletin for each of the various categories is published during January which lists all effective bulletins.

A typical aircraft technical bulletin as released by COMNAVAIRPAC is as follows:

COMMANDER AIR FORCE
UNITED STATES PACIFIC FLEET
U. S. NAVAL AIR STATION, NORTH ISLAND
SAN DIEGO, CALIFORNIA

NAVAIRPAC 7231
COMNAVAIRPAC GENERAL
AVIONICS BULLETIN NO. 14-56

INSTRUMENTS: PRESSURE TYPE ALTIMETER

1. Purpose. To disseminate information to prevent the intermixing of pointer type and counter pointer type altimeters within a squadron.

2. Cancellation of Previous Directives. None

3. Reference. (a) COMNAVAIRPAC msg 112331Z July NOTAL
(b) BUAER spdltr ser Aer-AE-7121 ser 011447 of 16 July 1957 NOTAL

4. Enclosure. None

5. Application. All aircraft (in particular, high performance aircraft).

6. Information. By reference (a), the Chief, Bureau of Aeronautics was advised that F4D-1 aircraft are being received in fleet activities with a Kollsman Counter Pointer type altimeter installed. The Section "B" allowance list and illustrated parts breakdown for the F4D-1 aircraft specifies the pointer type altimeter. Consequently pointer type altimeters are being substituted in F4D-1 aircraft for the counter pointer type. In addition, reference (a) advised that the intermixing of the two types of altimeter within the same unit was considered unsafe. Reference (a) advised that first deliveries of F4D-1 aircraft were with the standard three pointer altimeter, but that F4D-1 aircraft now being delivered would have the counter pointer type altimeter, and that earlier aircraft would have the counter pointer type installed during the interim modification program. Reference (b) further advised that the counter pointer type altimeter is presently in production for installation in all high performance aircraft, and that installation would be consistent with production quantities available.

7. Action. All units are directed to insure, wherever practicable, that only one type, either the pointer type or the counter pointer type altimeter is installed in all aircraft assigned.

8. Reports required. None

9. Log Book Entry. None

10. Cancellation of this Directive. When directed

COMNAVAIRPAC GENERAL
AVIONICS BULLETIN
NO. 14-56

SOURCES OF INFORMATION

There are a great number of publications that pertain to your work. If properly used, they provide very useful information that can be of much help. It is the responsibility of your maintenance officer to make these publications available to you. It is your responsibility to see that they are adequately used.

The following sources of information, with brief descriptive statements, should prove helpful and are given as a ready reference. A suggested method whereby general interest materials may be readily available is to place them in suitable binders and keep them in the shop.

AE 3 & 2, NAVPERS 10348.—This is a Navy Training Course written to supply the enlisted AE striker and the AE3 with the information he needs to perform the duties of his rate and to prepare him for advancement. It is a prerequisite to the material contained in this training course *(AE 1 & C)*. You should be thoroughly familiar with the contents of the *AE 3 & 2* training course.

AVIATION ELECTRICIAN'S MATE'S MANUAL, NAVAER 00-80T-59.—This is a manual that was prepared as the home study phase of the rate training course for Aviation Electrician's Mates of the Naval Air Reserve. It presents the basic principles of electricity and its applications to aircraft equipment. Specific attention is given to (1) the various means of providing and controlling power for aircraft systems, (2) aircraft instruments and instrument systems, (3) automatic pilots, and (4) maintenance techniques.

The manual is not written for a particular rate but is applicable to all of the rates within the rating. It is not as detailed as the Navy Training Courses *(Basic Electricity*, NavPers 10086; *Basic Electronics*, NavPers 10087; *AE 3 & 2*, NavPers 10348; and *AE 1 & C*, NavPers 10349) that have been written for the AE. However, it can be of much use when studying for advancement and for presenting general information.

U. S. NAVY SAFETY PRECAUTIONS, OPNAV 34P1.—This publication is a rather complete text on the subject of naval safety and is the result of compiling all directives and publications previously issued on the subject. All supervisory personnel should become familiar with the

chapters dealing with aviation and the chapter on electricity and electronics.

SUBSTITUTION GUIDE FOR ELECTRON TUBES, TRANSISTORS, AND RECTIFYING CRYSTALS.—This publication is a part of the Navy Stock Lists. It is Section FSC 596 (Federal Stock Catalog) of the Electronics Supply Office catalog. As the title implies, it is a guide that may be used to determine what respective tubes, transistors, or rectifiers may be used interchangeably. Directions to be followed when locating a substitute item are included on the back side of the cover sheet.

HANDBOOK OF OPERATION AND SERVICE INSTRUCTIONS ON AN ELECTRICAL CONNECTORS, AN 03-5-90.—This handbook covers the description, selection, preparation, installation, and maintenance instructions for commonly used AN connectors. It may serve as a source of general information for the electrician and also as a training guide for those inexperienced in the construction of cables using AN connectors.

INDEX-TRANSMISSION LINES AND FITTINGS, NAVSHIPS 900-102B (ASESA 49-29A).—This publication contains charts and tables which aid in the selection of proper cables and fittings to be used in constructing coaxial lines.

REDUCTION OF RADIO INTERFERENCE IN AIRCRAFT, NAVAER 16-1-521.—The purpose of this manual is to present information which will serve as a guide to the aviation industry and to naval aircraft maintenance activities for achievement and maintenance of the lowest practicable level of radio interference in naval aircraft. It may be used as a guide to enable you to determine the type of interference, to locate its source, and to provide a means for its elimination or suppression. The information is presented under the following headings:

1. Purpose.
2. Types and Effects of Radio Interference.
3. Sources of Radio Interference.
4. Interference Coupling.
5. Basic Installation Planning for Radio Interference Control.
6. Radio Interference Reduction Components; Their Selection, Application, and Installation.
7. Bonds and Bonding

8. Shields and Shielding.
9. Testing for Radio Interference.
10. Maintenance Aspects of Radio Interference.

HANDBOOK, AIRCRAFT INSPECTION REQUIREMENTS.—These handbooks contain complete requirements for periodic maintenance inspections and periodic replacement of accessories and components applicable to the aircraft to which the handbook pertains. They are used in the preparation of check sheets. These handbooks are of two types—(1) the *Handbook of Inspection Requirements Daily and Preflight* and (2) the *Handbook of Inspection Requirements Intermediate and Major*. Such handbooks are published for each particular model aircraft.

The *Handbook of Inspection Requirements Daily and Preflight* is composed of the master copy of the Daily and Preflight Inspection Check Sheet(s) for that aircraft. These check sheets break down the daily and preflight inspection by aircraft sections and systems.

The *Handbook of Inspection Requirements Intermediate and Major* is composed of two parts. Part 1 contains general instructions, definitions, special inspections, replacement schedules, and a listing of applicable references. Part 2 is a master copy of the Intermediate and Major Inspection Check Sheet(s), organized by systems, including entry space for additional work to be performed, discrepancies noted and corrected, and parts added and removed during the inspection.

HANDBOOK OF INSTALLATION PRACTICES FOR AIRCRAFT ELECTRIC AND ELECTRONIC WIRING, NAVAER 01-1A-505.—This handbook was written for the following purposes.

1. To gather together under one cover the recommended practices and techniques to be used for installing, repairing, and maintaining aircraft electric wiring.
2. To standardize these techniques and methods so that electrical installations will be done in a uniform manner.
3. To indoctrinate all personnel with the importance of good workmanship.
4. To point up the failures which may result from poor workmanship.
5. To promote safety by pointing out and prohibiting unsafe practices.

The information contained in the handbook represents the best current knowledge and practice in the aircraft electrical field. It has been compiled with the cooperation and assistance of the country's leading airframe manufacturers, airline operators, and military overhaul and repair bases. Many of the illustrations have been provided by the manufacturers of electrical accessories used in aircraft.

The topics covered are (1) wire and cable preparation, (2) general purpose connectors, (3) RF connectors and cabling, (4) solderless terminations and splicings, (5) thermocouple wire soldering and installation, (6) bonding and grounding, (7) bus bar preparation, (8) conduit fabrication, (9) installation of bus bars, conduit, junction boxes, protective devices, and terminal strips, (10) electrical wiring installation, (11) lacing and tying, (12) safety wiring and (13) emergency repairs.

You should make certain that copies of this handbook are readily available in the electric shop. It can be of much assistance to the leading petty officers for it contains the answers to many special maintenance problems. Also, it is an excellent source of information for the strikers and lower rated men and you should use it as a teaching aid in carrying out your on-the-job training duties.

AIRCRAFT ELECTRICAL POWER EQUIPMENT, NAVAER 17-15BA-500.—This is a handbook that provides instructions for the use of the standard test equipment that has been manufactured to test aircraft electric power equipment. The test equipment consists of an aircraft generator (drive) test stand and the aircraft electrical power equipment test assembly.

The handbook is divided into sections. Each section provides test procedures for a specific type of electrical power equipment. A complete test procedure for one basic model is given. The test procedure for the selected model is the most universal for the specific type of equipment. The basic portion of each section contains the following:

1. Description and leading particulars.
2. Typical test values.
3. Preparation for test, including any necessary inspections, checks, or maintenance operations.

4. Detailed step-by-step test procedures.

The sections of the handbook are as follows:

1. Introduction.
2. Test procedures for d-c generators.
3. Test procedures for d-c voltage regulators.
4. Test procedures for a-c d-c generators.
5. Test procedures for a-c generators.
6. Test procedures for a-c voltage regulators.
7. Test procedures for inverters.

NAVAL AERONAUTIC PUBLICATIONS INDEX, NAVAER 00-500, NAVAER 00-500A, NAVAER 00-500B.—This index is composed of three parts (three separate publications). A description of each part is given in the Navy Training Course *AE 3 & 2*, NavPers 10348, chapter 17, and will not be repeated here. Attention is given to the index in this course because with all probability, it can be of more help to you as a first class or chief than any other publication. For example, the information in the index can be used for determining what equipment is installed in a particular aircraft, for obtaining code numbers and titles when preparing orders for publications, and for many other uses. It contains a complete numerical listing of almost all of the publications that you will need in connection with aircraft electrical and instrument maintenance.

You must know how to properly use the index in order to obtain the best results. Instructions are contained in the front part of each section. By carefully studying these instructions and familiarizing yourself with the total contents of the index you will have a knowledge of the many uses that it can serve.

QUIZ

1. The aircraft inventory record is
   a. a Department of Defense publication
   b. prepared by the Aviation Supply Office
   c. prepared by the Bureau of Aeronautics
   d. a BuAer Publication bearing a NavAer designation applicable to each specific aircraft model

2. Which of the below items is NOT a function of source coding?
   a. Indicating where an item is stored
   b. Use of the next higher assembly
   c. Part to be locally manufactured
   d. Part is obtainable in supply system

3. The Naval Aeronautic Publications Index contains a listing of
   a. all current instrument and accessories bulletins
   b. all BuPers publications
   c. military specifications used by the Bureau of Aeronautics
   d. military information applicable to aircraft

4. The ComNavAir's, Atlantic and Pacific Fleets
   a. direct naval aviation
   b. establish policies regarding the organization, maintenance, and employment of fleet aviation
   c. are responsible for overhaul and maintenance of aircraft
   d. all of the above

5. The blue label on a screening tag denotes that the material is to be
   a. returned to salvage
   b. surveyed
   c. considered ready-for-issue
   d. returned to overhaul for reconditioning

6. Which of the following is a material reliability report?
   a. MRR
   b. FUR
   c. RUOM
   d. BuAer reliability digest

7. The Handbook of Installation Practices for Aircraft Electric and Electronic Wiring was written
   a. to promote safety
   b. to indoctrinate all personnel with good workmanship
   c. to point out failures resulting from poor workmanship
   d. all of the above

8. Electron tubes are controlled by the
   a. ASO
   b. ESO
   c. fleet command
   d. local command

9. The purpose of the material reliability program is to
   a. develop a historical record of material failures
   b. fix the blame for material failures
   c. perform statistical and technical analysis of equipment failures
   d. insure fleet awareness of material reliability
10. The Navy Stock List is a catalog of
   a. aviation stores
   b. general stores
   c. all Navy stores
   d. all federal stores
11. Ultimate consumer activities (carriers, FASRons, FAETU's, etc.) submit maintenance usage data reports
   a. every ninety days
   b. every two weeks
   c. every six months
   d. each month
12. The function of ASO is to
   a. issue aviation material
   b. publish Federal Cataloging Systems
   c. procure aviation materials
   d. stock aviation material
13. The <u>Aviation Electrician's Mate's Manual</u> (NavAer 00-80T-59) was written primarily for
   a. the Naval Reserve Aviation Electrician
   b. the AE3
   c. presenting maintenance techniques only
   d. correspondence course study
14. A formal survey board must include
   a. at least five persons, one of whom must be a commissioned officer
   b. one or more commissioned officers
   c. three members appointed by the custodian, plant account records
   d. one enlisted man
15. Specifications and standards are written primarily
   a. for the manufacturer
   b. for the operating activities
   c. to insure that products manufactured for the Navy meet certain requirements
   d. to enable O & R activities to more efficiently overhaul and repair aircraft
16. For obtaining its aeronautical materials, an aircraft carrier would be assigned to a
   a. reserve stock point
   b. distribution stock point
   c. secondary stock point
   d. primary stock point

17. Cognizance control symbol R is assigned to
    a. ASO
    b. ESO
    c. BuAer
    d. Forms and Publications Supply Office
18. When property is to be re-evaluated or expended from the records
    a. a survey must be made to obtain proper authority to write the material off the books
    b. a request is turned in to the Material Office and equipment is turned in as class 265 for screening
    c. information to show condition of equipment must be submitted to the Maintenance Officer
    d. a FUR or EFR should be made out on the equipment
19. Military standards contain information that relates to
    a. products or services used only by military activities
    b. information formerly contained in Joint Army-Navy Specifications
    c. engineering practices, charts, graphs, formulas, and lists
    d. information obtained from military specifications
20. Supply lists that are used when commissioning or reactivating an activity are referred to as
    a. usage data lists
    b. Navy stock lists
    c. availability lists
    d. allowance lists

CHAPTER 3

ADVANCED ALTERNATING-CURRENT THEORY

The first part of this chapter deals with basic a-c functions, circuit characteristics, and definitions. These topics are fully explained in *Basic Electricity*, NavPers 10086; however, they are briefly reviewed in this chapter for purposes of continuity between *Basic Electricity* and *AE 1 & C*. Basic a-c theories and relations must be thoroughly understood before you can make effective progress in studying the more complex relations and mathematical processes.

The latter part of this chapter deals with the solution of a-c problems by use of complex quantities which are represented by rectangular and polar vectors. This is not discussed in any other Navy Training Courses that you are required to study. You should be able to use these forms of mathematics before beginning the study of polyphase systems. Rectangular and polar quantities will be used to analyze and explain polyphase systems and machinery.

VECTOR ANALYSIS OF VOLTAGE AND CURRENT

Vector Representation of Voltages

INDUCTIVE IMPEDANCE.—An inductive impedance may be a single coil, or a complex network whose over-all characteristics are inductive in nature. All such

impedances, however, have at least one characteristic in common—they will not permit their currents to change rapidly enough to coincide with changes in the impressed voltage. As a result, the current wave through an inductive impedance never quite catches up with the wave of impressed voltage. This is commonly referred to as a current "lag," and in a theoretically pure inductance, with no resistive loss whatsoever, this lag would amount to a full 90°. In practice, however, there is also some opposition to current flow which is resistive in nature. In a purely resistive impedance, there will be no angular difference between the current wave across the resistor and the wave of impressed voltage. Thus, in a theoretically pure resistance, the angular difference between current and voltage waves across the resistor would amount to 0°. From the foregoing, you can see that an impedance comprised of elements which are both resistive and inductive would cause a circuit current lag of an amount between 0° and 90°. The amount of lag would depend on the ratio of inductive reactance to resistance at a given frequency.

PHASE ANGLE AND POWER FACTOR OF AN INDUCTIVE IMPEDANCE.—The angular difference (phase angle) between circuit current and impressed voltage has a direct bearing on the amount of power (watts) actually dissipated in a partially inductive impedance. Resistive opposition to current flow constitutes an actual power loss, because energy is dissipated in the form of heat. Inductive opposition to current flow does not cause a power loss, because energy is transferred alternately to and from the magnetic field formed around the inductor.

The energy stored in this field during one-half of an alternating cycle is returned by induction during the other half of the same cycle, so that the average loss equals zero. Thus, the amount of actual power loss (true power) in a partially inductive impedance depends on the ratio of resistance to inductance. The true power in a circuit also depends on how the various elements are connected in relation to each other. The effects of changing connections will be discussed later. Figure 3-1 is used to show how power loss is affected by the ratio of resistance to inductance.

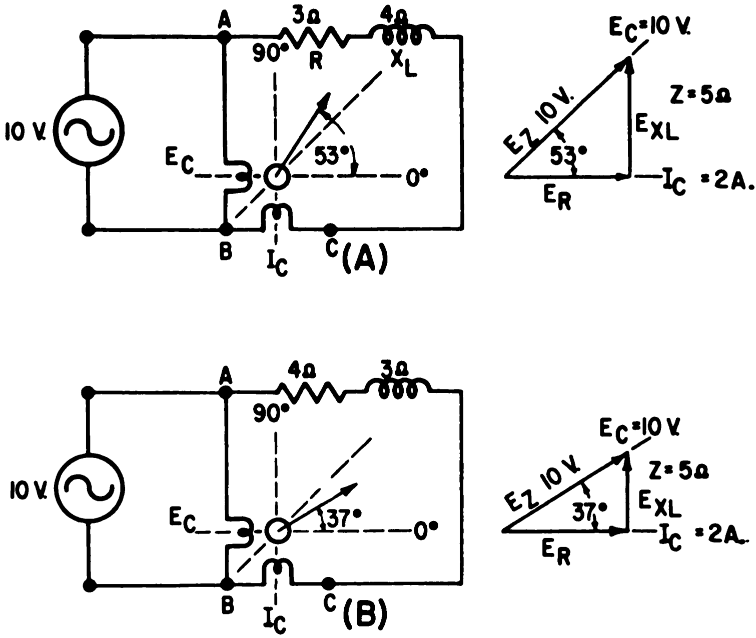


Figure 3-1.—Vector representation of voltages in an inductive impedance.

Both (A) and (B) in figure 3-1 represent simple impedances with inductive characteristics. In both cases, applied voltage is the same (10 volts). Also, total circuit impedance (5Ω) and line current (2 a.) are the same. If an ordinary a-c voltmeter were connected across points *A* and *B* and an ammeter between points *C* and *B*, identical readings of voltage and amperage would be obtained from both circuits. At a glance, it might seem that both circuits are consuming identical amounts of power. This is not true. The vector diagrams represent the average relative magnitude of resistive and inductive voltage drops. More important, they also show the differing phase angles of the two circuits. This difference is significant.

Coils E_C and I_C are arranged so that if the voltage wave through E_C is completely in phase with the current wave through I_C, maximum meter torque will result.

The indicator would point to 0°. Conversely, if the voltage and current waves were a full 90° out of conjunction (phase), meter torque would be minimum and the indicator would point to 90°. SINCE THE TRUE POWER IN AN A-C CIRCUIT IS DIRECTLY INDICATED BY THE PHASE ANGLE, THIS "PHASE ANGLE INDICATOR" MAY BE CALIBRATED IN WATTS.

Vector diagrams may be used to determine phase angle. Once the angle is known, its numerical cosine may be multiplied by 100 to yield a percentage figure, or "power factor." This figure indicates directly what percentage of apparent power is dissipated in heat, and thus indirectly what percentage is merely a circulating interchange of energy between the voltage source and the circuit inductance.

The numerical cosine may also be multiplied by line voltage and current to obtain true power in watts. This would be done where the actual number of watts must be known, rather than the percentage of true power to apparent power. Vectors serve well in analyzing simple circuits, but would be clumsy if used in complex problems. However, complex processes are based on the fundamental a-c relations usually represented by vectors. Before commencing the study of rectangular and polar notation, you must be thoroughly familiar with these basic relations.

CAPACITIVE IMPEDANCE.—A capacitive impedance may be a single capacitor or a complex network whose overall characteristics are capacitive in nature. A characteristic common to all capacitive impedances is that they will not permit their voltages (capacitor charge) to change rapidly enough to coincide with changes in the impressed current. As a result, the current wave through a capacitive impedance is always ahead of the wave of voltage across the same impedance. This is commonly referred to as a current "lead."

In a theoretically pure capacitance, with no resistive loss whatsoever, this lead would amount to a full 90°. In practice, however, there is always some opposition to current flow, which is resistive in nature. The current could never attain a full 90° lead, though some high quality capacitors approach it very closely. Consequently, the phase angle of a capacitive impedance will depend on

the ratio of resistance to capacitance at a given frequency.

PHASE ANGLE AND POWER FACTOR OF A CAPACITIVE IMPEDANCE.—The angular difference (phase angle) between circuit current and voltage has a direct bearing on the amount of power actually dissipated in a partially capacitive impedance. The phase angle, and thus true power, is again determined by the ratio of reactance to resistance; in this case the reactance being capacitive in nature.

Refer again to figure 3-1. If the inductors in both circuits were replaced by capacitors of the same ohmic reactive values (4 Ω and 3 Ω), the phase angle in both cases would remain the same. The magnitude of line current and true power in each circuit would also be unchanged. There would be, however, one significant difference—rather than current (I_C) lagging voltage (E_C), the relation would be reversed. Current would lead voltage, but still by the angles indicated.

The apparent opposition to current flow evidenced by the capacitor (capacitive reactance) does not constitute an actual power loss. As with the inductance, there is a reciprocating interchange of energy between the capacitance and source of impressed voltage, with a net energy (power) loss of zero. Energy is alternately stored and released by the capacitor's electrostatic field (charge) rather than by a magnetic field such as that in an inductor.

INDUCTIVE AND CAPACITIVE IMPEDANCE.—An impedance may have individual elements or branches which, in themselves, may be inductive or capacitive in nature. In such a case, however, the overall characteristic of the impedance is determined by the ratio of inductance to capacitance.

Figure 3-2 (A) represents an impedance composed of both inductive and capacitive elements, as well as resistance. The voltage from points A to B is always 180° out of phase with the voltage from points B to C, assuming both reactances are pure. Consequently, one may be subtracted algebraically from the other, as shown in the accompanying vector diagram. The resultant net reactive voltage, identified as $E_{XL} - E_{XC}$ in part (A) and as $E_{XC} - E_{XL}$ in part (B), determines the overall characteristic of the circuit. That is, part (A) is inductive in nature, while

part (B) is capacitive. THE TRUE POWER IS THE SAME IN EITHER CIRCUIT. True power is determined by the phase angle. It does not matter whether current is leading or lagging. The wattmeter is deflected the same amount and in the same direction in either case, and cannot differentiate between an inductive or capacitive load.

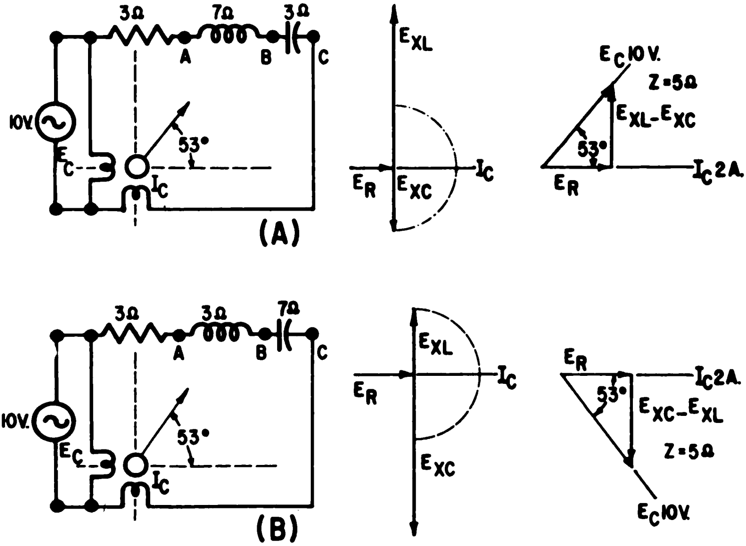


Figure 3-2.—Vector representation of voltages in an inductive and capacitive impedance.

Vector Representation of Currents

In representing voltage vectors, series impedances were used, and circuit (line) current was used as a reference. This was done because only one current flows through the entire series circuit. Thus, the various element voltages could be shown in relation to a common reference (current), and consequently in relation to each other. When solving or representing more than one current, however, it must be assumed that a parallel circuit is under consideration. Only in a parallel circuit may there be more than one current simultaneously.

Parallel branches connected to a common source have the same voltage applied across their terminals. For this reason, line voltage is used as a reference for laying out branch currents to show their relation to a common reference and to each other. In series, conflicting element voltages are resolved with impressed voltage to produce a common line current. In parallel impedances, conflicting element currents resolve into a single line current, and in some cases circulating currents, but all elements have a common terminal voltage.

In figure 3-3, the magnitude of each branch current may be obtained by simply dividing the line voltage by branch resistance, or reactance. Capacitive current is shown leading line voltage because it is characteristic for the current in any capacitive reactance to lead the voltage across its terminals.

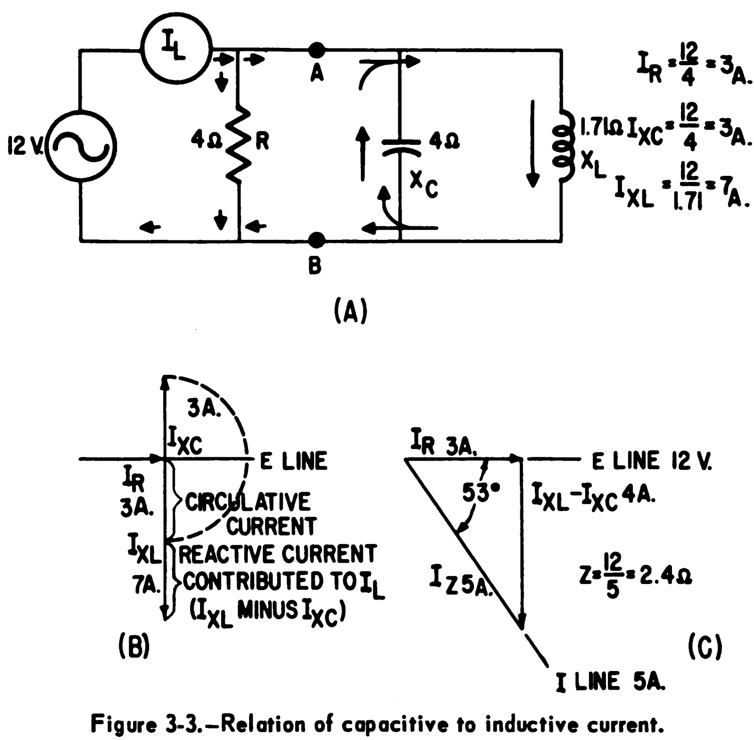


Figure 3-3.—Relation of capacitive to inductive current.

The inductive current lags because of its inductive nature. The current vectors shown in (B) represent individual branch currents. I_{XC} and I_{XL} are 180° out of phase, and so may be subtracted algebraically to obtain the reactive current value represented by I_{XL} - I_{XC} in (C). Their algebraic difference constitutes the actual value of current flowing from points A to B through X_C and X_L in part (A). That is, the reactive component of I_L is contributed to the circuit through points A and B, but the circulating interchange of current between X_C and X_L may be smaller, equal to, or larger than the reactive current component on the line. As can be seen, the overall circuit characteristic will be determined by which reactive branch current is the larger.

The impedance of figure 3-3 has an overall inductive characteristic. No power is used in the theoretically pure capacitive and inductive branches. Energy is dissipated across the resistor only, which is connected directly to the voltage source, and is thus relatively free from reactive influences. The reactive branches may be varied at will without changing the true power of the circuit as a whole. Assuming line voltage is fixed, energy current I_R would remain fixed; line current I_L would vary with changes in either X_C or X_L. If reactive current I_{XL} - I_{XC} ((C) of fig. 3-3) became greater, then line current I_L (I_Z in (C)) would also become somewhat greater. However, the compensating factor, as far as true power values are concerned, is the fact that angle θ would also increase. As this angle increases, its numerical cosine decreases. In the formula for determining true power—volts × amps × cosine of phase angle ($V \times A \times \cos\theta = P$)—note that if line amperage (A) increases, and the cosine of circuit phase angle ($\cos\theta$) decreases a proportional amount, true power (P) remains the same.

ENERGY AND REACTIVE CURRENTS.—In practical circuits, there will be no purely reactive loads or branches. That is, some true power will be consumed by any load placed on a power source, such as an a-c generator or inverter. In addition, there will usually be a reactive, or VARS, load. Since the generator or inverter is supplying maximum power to its load when current

and voltage are in phase, it is important that the power factor be kept as high as possible.

The load rating of an a-c machine is determined primarily by the internal heat it can withstand for long periods of time. The current through its windings is the major cause of heating. For this reason, a-c generators and inverters are rated in volt-amperes rather than in watts. A given magnitude of line current will cause a specific amount of heating, regardless of whether it is "energy" current or "reactive" current. A current which is out of phase with its voltage is said to be composed of two components—energy current and reactive current. If a generator is supplying a highly reactive load, it may be operating at its maximum allowable line amperage, and still not be delivering the proper amount of true power. More useful loads could not be added under these circumstances without exceeding the load rating of the generator.

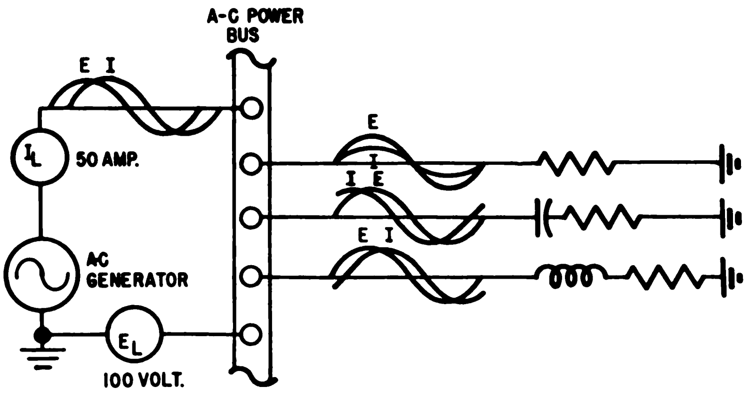


Figure 3-4.—A-c generator supplying a multibranch load.

Figure 3-4 represents an a-c generator supplying a partially reactive load. Each load branch has a different current characteristic than the other branches. Assuming the generator shown is rated at 5,000 VA, then it is supplying its full rated load. Figure 3-5 is a more complete representation of the same circuit.

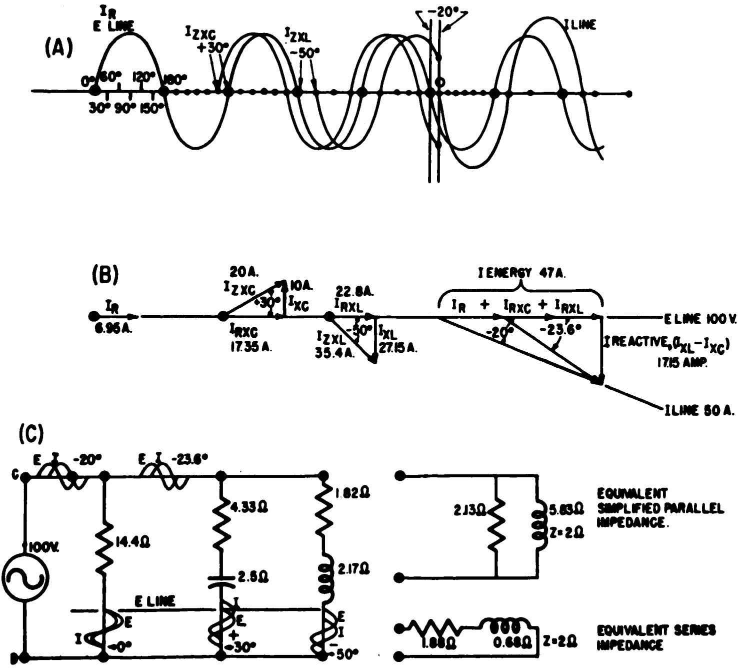


Figure 3-5.—Representation of multibranch currents.

Part (A) of figure 3-5 represents the progressive combining of separate branch currents, shown in sine wave form, into a single final line current wave, (I_{line}). Part (B) represents the same currents shown in vector form. Note that each reactive branch current is composed of both energy current (I_{RXC} and I_{RXL}) and reactive current (I_{XC} and I_{XL}). The subtriangle formed by I_{RXC} + I_{RXL} on one side and I_{XL} - I_{XC} on another represents the phase relations of the reactive branches only. The true power in the reactive branches equals I_{RXC} (17.35 + I_{RXL} (22.8) × 100v. (17.35 + 22.8 × 100 = 4,015 watts.) VARS in the reactive branches equals I_{XL} (27.15) - I_{XC} (10) × 100v. (27.15 - 10 × 100 = 1,715 VARS.) True power for the whole circuit is obtained when I_R is added to the complete triangle (4,700 watts). VARS remains the same, because the current through the resistive branch contains no reactive components.

The whole a-c load, as far as the generator is concerned, could be reduced to the equivalent impedances shown in part (C). If power factor correction is to be made for a particular a-c generator or inverter, it is best to reduce the machine's load to a single simplified impedance in order to determine the nature and magnitude of correction to be made.

Assume that an additional resistive load must be connected to the a-c generator considered in figure 3-5. None of its existing loads may be disconnected. Since the generator is already operating at maximum rated current, this might seem impossible. Refer to figure 3-6 in connection with the following explanation. Part (A) represents the simplified load impedance before correction is made.

The generator is delivering 4,700 watts of power, and its line current is 50 amps. Obviously, no additional load

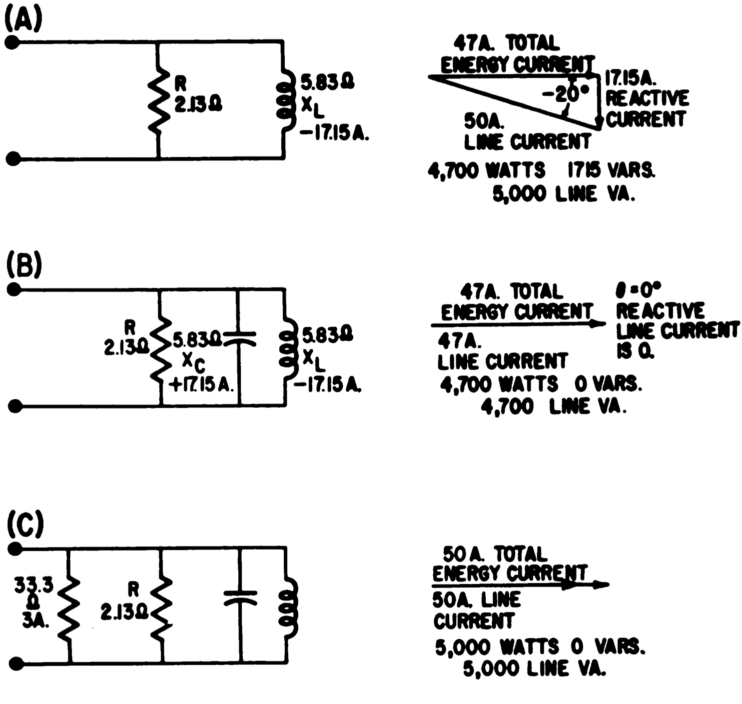


Figure 3-6.—Simplified impedances for balancing reactive loads.

can be connected without overloading the generator. In part (B), capacitive correction is connected; this causes the reactive component of line current to be reduced to zero. Circulating current at this point is increased, between the reactive elements of the generator's load, but line current through the generator is decreased from 50 amps to 47 amps. An additional useful load up to 3 amps may then be connected as shown in part (C).

RECTANGULAR NOTATION OF A-C QUANTITIES

Definition of Rectangular Vectors

Up to this point, vectors have been described as shown in figure 3-7 (A). That is, they have been visualized essentially as the hypotenuse of a right triangle. When described in this manner, a vector's magnitude, or length, from point O to A is given. In addition, its direction is also given as the number of degrees that the vector is laying away from a horizontal reference line. The number of degrees is symbolized by theta (θ). This is the polar vector form. When the polar form is used, a vector is described in terms of its magnitude and direction. For instance, a vector 10 inches long laying at 30° above the horizontal line would be described as $10\underline{/30°}$. ($\underline{/\ }$ symbolizes "at an angle of"). If the magnitude of vector OA in figure 3-7 (A) is known and θ is also known, the length of sides R and J could be determined, if required, by the use of trigonometry.

Vector OA could also be accurately described in another manner, if only the length and direction of sides R and J are known. This method is illustrated in figure 3-7 (B). In this case, neither the actual length of vector OA nor θ is known. Nevertheless, vector OA may still be accurately referred to as vector $R8.66 \oplus J5$, because $R8.66$ and $J5$ form a triangle of which vector OA is the hypotenuse. (The symbol $\oplus$ means added vectorially). Later, you will process vector quantities mathematically, using a similar form, without necessarily ever knowing the actual magnitudes and directions of the vectors on which you are working. They will simply be written in

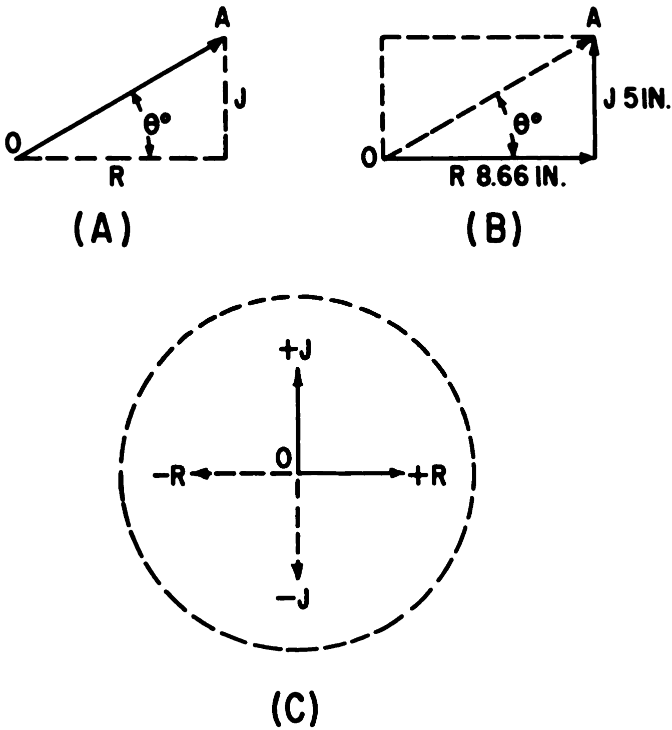


Figure 3-7.—(A) Polar vector; (B) rectangular vector; (C) directional axes for rectangular vectors.

terms of their components, or sides. If vectors *R* and *J* are considered as two sides of a rectangle as shown in figure 3-7 (B), then vector *OA* is the diagonal length of that rectangle; hence the term rectangular vector.

Since rectangular notation must be able to indicate direction as well as magnitude, then vector *R* must be able to lay either to the right or left of point *O*, as shown in figure 3-7 (C). Also, vector *J* must be able to lay either above or below point *O*. When vector *R* is to the right, it is given a positive (+) sign, or a negative (-) sign when laying to the left. Vector *J* is given a positive (+) sign when above the line, or a negative (-) sign when below. In this way, the distance and direction of a point anywhere within a circle, in relation to the middle of the

circle, may be indicated by the signs and lengths of vectors R and J. This is given further illustration in figure 3-8.

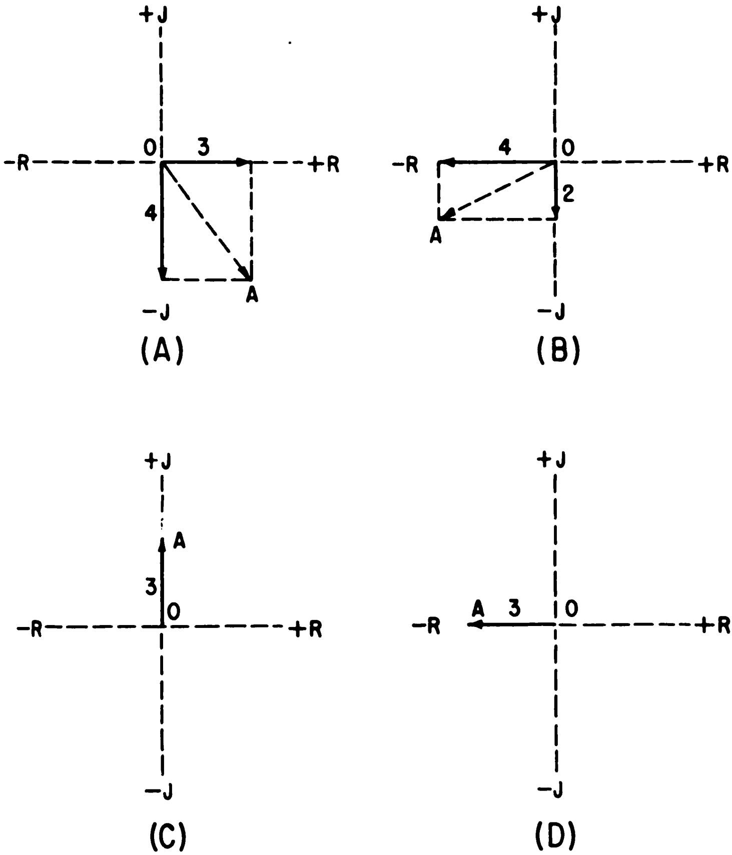


Figure 3-8.—Representation of rectangular vectors.

In part (A), vector OA is referred to as vector $R3 - J4$. In part (B) vector OA is referred to as vector $-R4 - J2$. In part (C), vector OA is $0 + J3$; and in (D), it is $-R3 + J0$. Note that when a vector is perfectly vertical or horizontal, its rectangular description still contains two components, but one is included only as a zero value. In practice, THE HORIZONTAL, OR R, COMPONENT IS ALWAYS STATED

FIRST, AND THE VERTICAL, OR *J*, COMPONENT IS STATED SECOND. Also, the *R* is dropped, but its algebraic sign is kept. The *J* is never dropped, however. Therefore, vector *OA* in figure 3-8 (A), for instance would be referred to more simply as 3 - *J*4, and that in (B) would be referred to as -4 - *J*2.

Use of Rectangular Vectors

Rectangular vectors are commonly used to describe and identify a-c quantities in terms of their components. These quantities include impedance, admittance, current, voltage, and power. When expressing an impedance in rectangular form, the resistive component is always the first member, and the reactive component is the second, or *J* member. Also, rectangular representation of impedance ALWAYS refers to components connected in SERIES. THERE IS NO SUCH THING AS AN IMPEDANCE VECTOR FOR PARALLEL COMPONENTS. Total parallel impedance is solved only by dividing total current into line voltage. Figure 3-9 shows the various types of series impedances, and to the right of each appears the three common methods of representing each.

Referring to figure 3-9, note that impedances which are inductive in nature are different from those which are capacitive in the following significant way—the operator *J* is positive (+*J*) for inductive impedances and is negative (-*J*) for capacitive impedances. This is quite logical and easily remembered if you consider the voltage drops as they would occur across these impedances if they were connected in a circuit. That is, voltage leads (+*J*) across an inductance, and lags (-*J*) across a capacitance. Therefore, the algebraic sign of the *J* operator is the same for both voltage and impedance when these values are represented for a given circuit. The algebraic sign itself is determined by the reactive nature of the circuit. This may be seen clearly by comparing the algebraic signs of the *J* operators as they appear in the IMPEDANCE and VOLTAGE columns of figure 3-10. In summary, a plus (+*J*) is used for an inductive impedance or inductive voltage drop, and a minus (-*J*) is used for a capacitive impedance or capacitive voltage drop. Also, resistive voltage components are written first, while

IMPEDANCE	VECTOR FORM	RECTANGULAR FORM	POLAR FORM
$R=5\Omega$	$R=5\Omega$	$Z=5+J0\Omega$	$Z=5\angle 0°\ \Omega$
$X_C=7\Omega$	$X_C=7\Omega$	$Z=0-J7\Omega$	$Z=7\angle -90°\Omega$
$X_L=6\Omega$	$X_L=6\Omega$	$Z=0+J6\Omega$	$Z=6\angle +90°\Omega$
$R=6\Omega$ $X=8\Omega$	X_L Z R	$Z=6+J8\Omega$	$Z=10\angle +53.1°\ \Omega$
$R=8\Omega$ $XC=6\Omega$	X_C R Z	$Z=8-J6\Omega$	$Z=5\angle -36.9°\Omega$
$R=2\Omega X_C=7\Omega$ $R=2\Omega\ X_L=4\Omega$	R+R Z X_C-X_L	$Z=4-J3\Omega$	$Z=5\angle -36.9°\Omega$

Figure 3-9.—Common methods of representing impedance.

reactive voltages are always written second and preceded by $\pm J$, as the case requires.

Refer again to figure 3-10. Notice that current and power notations for each circuit have their J operators preceded by algebraic signs which are opposite to those which refer to impedance and voltage. (Except in the top row, where the J factor is 0, and the algebraic sign is thus unimportant.) Again, there is a logical reason for this, because the current through an inductance has a lagging ($-J$) characteristic, while current through a capacitance is leading ($+J$). The nature of a current may thus be indicated by the algebraic sign of its J factor. This would also provide a direct indication of the nature of the impedance through which the current is flowing

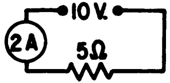
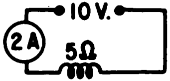
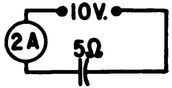
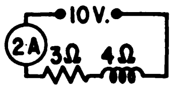
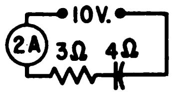
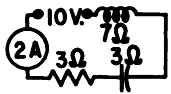
CIRCUIT	IMPEDANCE	VOLTAGE	CURRENT	POWER
	Z=5Ω OR Z=5+J0Ω	E_L=10 V. OR E_L=10+J0V.	I_L=2A. OR I_L=2+J0A.	AP=20 WATTS OR AP=20+J0W.
	Z=5Ω OR Z=0+J5Ω	E_L=10 V. OR E_L=0+J10V.	I_L=2A. OR I_L=0−J2A.	AP=20 WATTS OR AP=0−J20W.
	Z=5Ω OR Z=0−J5Ω	E_L=10 V. OR E_L=0−J10V.	I_L=2A. OR I_L=0+J2A.	AP=20 WATTS OR AP=0+J20W.
	Z=5Ω OR Z=3+J4Ω	E_L=10V. OR E_L=6+J8V.	I_L=2A. OR I_L=1.2−J1.37A.	AP=20 WATTS OR AP=12−J16W.
	Z=5Ω OR Z=3−J4Ω	E_L=10V. OR E_L=6−J8V.	I_L=2A. OR I_L=1.2+J1.37A.	AP=20 WATTS OR AP=12+J16W.
	Z=5Ω OR Z=3+J4Ω	E_L=10V. OR E_L=6+J8V.	I_L=2A. OR I_L=1.2−J1.37A.	AP=20 WATTS OR AP=12−J16W.

Figure 3-10.—Rectangular notation of a-c quantities.

(inductive or capacitive). When a current is represented in rectangular form, the first member indicates the energy (watt) component, while the J member indicates the reactive (VARS) component. This is one of the many convenient features of rectangular notation. That is, a direct indication of the true power to apparent power ratio is shown simply by describing the current in terms of its rectangular components. The close resemblance of a current vector to a power vector becomes apparent if you notice that both have identical algebraic signs preceding the J operator. The triangles inferred by both vectors will have the same shape and phase angle θ, though their actual magnitudes may differ.

When circuit power is expressed in rectangular form, the first member represents true power in watts, and the J member represents reactive volt-amperes (VARS).

The discussion up to this point has involved only the identification of a-c quantities in rectangular form. Some fundamental advantages have also been discussed. However, no mention has been made of the most important single advantage gained by the use of rectangular vectors, which is as follows: A-C QUANTITIES REPRESENTED AS RECTANGULAR VECTORS MAY BE PROCESSED MATHEMATICALLY WITHOUT DIRECT USE OF TRIGONOMETRIC FUNCTIONS. THE MULTIPLICATION, DIVISION, ADDITION, AND SUBTRACTION OF A-C QUANTITIES CAN BE CARRIED OUT BY TREATING THESE QUANTITIES AS SIMPLE BINOMIALS.

ADDITION OF RECTANGULAR VECTORS.—Addition of rectangular vectors is accomplished in the following manner.

<u>Example:</u>

Add $4 + J6$ to $-6 + J7$

<u>Solution:</u>

$$\begin{array}{r} 4 + J6 \\ -6 + J7 \\ \hline -2 + J13 \end{array}$$

(answer).

SUBTRACTION OF RECTANGULAR VECTORS.—Subtraction of rectangular vectors is accomplished as follows:

Example:

Subtract $6 - j9$ from $-2 - j7$

Solution:

Change the signs of the subtrahend $6 - j9$ to $-6 + j9$, then—

$$
\begin{array}{l}
-2 - j7 \\
-6 + j9 \\
\hline
-8 + j2 \text{ (answer).}
\end{array}
$$

MULTIPLICATION OF RECTANGULAR VECTORS.—In multiplying rectangular vectors, the rules applying to multiplication of simple binomials still apply. This is done in the following manner:

Example:

Multiply $7 - j6$ by $4 + j8$

Solution:

(1)
$$
\begin{array}{rrr}
7 & -j6 & \\
4 & +j8 & \\
\hline
28 & -j24 & \\
 & +j56 & -j^2 48 \\
\hline
28 & -j32 & -j^2 48
\end{array}
$$

(2) $28 - j32 + 48$

(3) $76 + j32$ (answer).

RULE FOR MULTIPLYING RECTANGULAR VECTORS.—When a member of the product is preceded by a

j^2, such as in the last line of step (1) in the foregoing problem, the j^2 is dropped and its sign reversed, as shown in step (2). The member is then combined to obtain the final answer, as shown in step (3).

DIVISION OF RECTANGULAR VECTORS.—The division of rectangular vectors is the most complex of the four mathematical operations.

<u>Example:</u>

Divide $50 + j35$ by $8 + j5$.

The first step is to convert the divisor $8 + j5$ into a single number unaffected by the operator j. This is done by multiplying the divisor by its conjugate, $8 - j5$. (The conjugate of any rectangular vector is that vector with the sign of its j operator reversed.) Multiplying any rectangular vector by its conjugate will produce a single number. For instance, $8 + j5 \times 8 - j5 = 64 - j^2 25$, or 89. Any fraction may have its numerator and denominator multiplied by the same number or quantity without affecting the value of the fraction. For instance, $3/8 \times 4/4 = 12/32 = 3/8$. Therefore, both numerator and denominator of the original example problem $50 + j35/8 + j5$ may be multiplied by the conjugate of the divisor without changing its value, as follows:

$$\frac{50 + j35}{8 + j5} \times \frac{8 - j5}{8 - j5} = \frac{400 + j30 - j^2 175}{64 - j^2 25}.$$

This operation, after terms are collected, results in the original $50 + j35/8 + j5$ having been changed to the new form $575 + j30/89$. When each member of the numerator is divided by 89, the result is

$$6.46 + j0.337 \text{ (answer).}$$

POLAR NOTATION OF A-C QUANTITIES

Definition of Polar Vectors

A polar vector may be any ordinary vector. It is different from an identical rectangular vector only in the

manner in which it is described. A vector in polar form is given in terms of its length, or magnitude, and the angle formed between the vector and a reference line. Refer again to figure 3-7. If the vector *OA* in part (A) was 10 units in length, and θ was 45°, then vector *OA* would be written in polar form as $10\underline{/45^\circ}$. The symbol $\underline{/\quad}$ means "at an angle of."

Use of Polar Vectors

Polar vectors are used to identify a-c quantities in much the same manner as rectangular vectors. The major difference in the two forms lies in the specific components of a quantity which are identified. (Refer to fig. 3-11.) Note that when an impedance is represented in rectangular form, the components such as resistance and reactance are given, with overall impedance and phase angle implied. When the same impedance is represented in polar form, the overall impedance and phase angle are given, and the resistive and reactive components are implied.

ADDITION AND SUBTRACTION OF POLAR VECTORS.—Vectors expressed in polar form can be added or subtracted by graphical methods only, unless their directions are parallel. To add or subtract them algebraically, they must be converted to rectangular form. Conversion of one form to another will be discussed later.

MULTIPLICATION OF POLAR VECTORS.—The product of two polar vectors is obtained by multiplying their magnitudes and adding their angles.

<u>Example:</u>

Multiply $8\underline{/20^\circ}$ by $20\underline{/-35^\circ}$

<u>Solution:</u>

$$\begin{array}{r} 8 \\ \underline{20} \\ 160 \end{array} \qquad \begin{array}{r} 20^\circ \\ \underline{+(-35^\circ)} \\ -15^\circ \end{array}$$

$160\underline{/-15^\circ}$ (answer).

DIVISION OF POLAR VECTORS.—The quotient of two polar vectors is obtained by dividing their magnitudes and subtracting the angle of the divisor from the angle of the dividend.

Example:

Divide $30\underline{/20°}$ by $2\underline{/30°}$.

Solution:

$$\frac{30}{2} = 15 \qquad \begin{array}{r} 20° \\ -(30°) \\ \hline 10° \end{array}$$

$$15\underline{/-10°} \text{ (answer)}$$

Conversion of Forms

You have probably observed that certain forms of notation lend themselves more readily to one mathematical operation than to another.

For instance, the multiplying and dividing of rectangular vectors involve rather complex operations if compared to the multiplying and dividing of polar vectors. On the other hand, algebraic addition and subtraction of rectangular vectors involve relatively simple operations, whereas it cannot be done at all with polar vectors. Obviously, there are occasions when one form must be converted to the other. This is done in the following manner.

CONVERSION FROM RECTANGULAR TO POLAR FORM.—As previously stated, if rectangular members are considered to be two sides of a right triangle, then the hypotenuse and angle θ for any such triangle is directly implied by the given sides. To determine the value of the hypotenuse, you must first determine the angle θ. Angle θ is determined by first obtaining the value of its tangent, then locating this tangent value on table of trigonometric functions. (There is a table of trigonometric functions in appendix I of this book.) The tangent of angle θ can always be obtained by dividing the rectangular j member by the first, or energy, member.

For instance, to obtain the tangent of the angle implied by $3+j4$, divide $j4$ by 3. That is,

$$\tan\theta = \frac{j4}{3}, \text{ or } 1.33.$$

If you locate the tangent value of 1.33 on the table of trigonometric functions, you will find that it is the tangent of 53.1°. You may state, then, that the angle θ for the vector $3+j4$ is 53.1°. After finding θ, the next step is to determine the length, or value, of the hypotenuse. This may be done in either of two ways. The hypotenuse is equal to the energy member divided by the cosine of 53.1°, or it is also equal to the j member divided by the sine of 53.1°. If $3+j4$ represented an impedance, then the hypotenuse (total impedance) could be written as follows:

$$Z = \frac{3}{\cos 53.1^\circ} \text{ or } Z = \frac{j4}{\sin 53.1^\circ}.$$

The numerical value of the sine or cosine of θ is obtained by consulting the table of trigonometric functions. Notice that the tangent, sine, and cosine for a given angle are all printed adjacent to one another. Since the cosine of 53.1° is 0.600, and the sine is 0.800, then

$$Z = \frac{3}{0.6} \text{ or } Z = \frac{j4}{0.8}.$$

In either case, $Z = 5$. Thus, when the rectangular vector $3+j4\ \Omega$ is converted to a polar vector, it becomes $5\underline{/53.1^\circ}\ \Omega$.

CONVERSION FROM POLAR TO RECTANGULAR FORM.—This conversion is somewhat simpler, since angle θ is known at the start. In the polar vector $10\underline{/-53.1^\circ}$, the number 10 is considered to be the hypotenuse of a right triangle, and the angle θ is given as -53.1°. The implied remaining sides (rectangular members) are found as follows: The first (energy) member is found by multiplying the hypotenuse by the cosine of θ. The second, or j member, is found by multiplying the hypotenuse by the sine of θ. The algebraic sign of the resulting

j member is the same as the sign of the given angle. The polar vector $10\underline{/-53.1^\circ}$ would thus be written in rectangular form as

$$(10 \times \cos 53.1^\circ) - j(10 \times \text{sine } 53.1^\circ),$$

or

$$(10 \times 0.6) - \quad (10 \times 0.8) = 6 - j8.$$

APPLICATION OF RECTANGULAR AND POLAR NOTATION

As previously stated, a-c quantities represented in rectangular and polar form may be processed mathematically in that form, without direct use of trigonometric functions. Trigonometry will be used only if one form is converted to another.

It is important to note that these complex forms, when processed mathematically, are used in exactly the same manner, in relation to one another, as simple d-c quantities. For instance, suppose you were to solve an a-c problem involving an impedance of $2 - j3\ \Omega$, a current of $6 + j4$ amps, and a voltage of $24 - j10$ volts. Ohm's law states:

$$I = \frac{E}{Z},$$

or

$$E = I \times Z,$$

and

$$Z = \frac{E}{I}.$$

The same law applies in the solution of a-c problems, except that Z, I, and E are given in the more complex rectangular or polar forms. For instance (with all quantities given in complex form), since

$$\frac{E}{Z} = I$$

then

$$\frac{24 - j10 \text{ volts}}{2 - j3 \text{ ohms}} = 6 + j4 \text{ amps.}$$

Solution of Series Circuits

Assume that a voltage of $208 + j0$ volts is impressed on the series circuit shown in figure 3-11. Determine the following: (A) impedance, (B) current, and (C) phase angle.

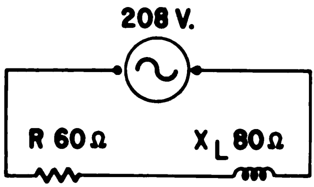


Figure 3-11.—Simple series circuit.

<u>Solution</u>: Impedance is $60 + j80\ \Omega$ (A)

Since current is

$$I = \frac{E}{Z}$$

therefore,

$$I = \frac{208 + j0}{60 + j80}$$

$$= \frac{208 + j0}{60 + j80} \times \frac{60 - j80}{60 - j80}$$

$$= \frac{12{,}480 - j16{,}640}{10{,}000}$$

$$= 1.24 - j1.66 \text{ amps.} \qquad \text{(B)}$$

The phase angle is determined by first obtaining its tangent as follows:

$$\tan\theta = \frac{-j1.66}{1.24} = -1.33.$$

The number 1.33, when located on the table of trigonometric functions indicates 53.1°. The minus sign indicates a -53.1°. Therefore,

$$\text{phase angle} = -53.1°. \qquad \text{(C)}$$

To determine (A), (B), and (C) in polar form, first convert the rectangular impedance $60 + j80\,\Omega$ into polar form.

$$\tan\theta = \frac{j80}{60} = 1.33 = \text{tangent of } 53.1^\circ$$

$$\text{polar magnitude} = \frac{60}{\cos 53.1^\circ} \text{ or } \frac{j80}{\sin 53.1^\circ} = 100.$$

Therefore,

$$\text{polar impedance} = 100\underline{/53.1^\circ}. \qquad \text{(A)}$$

Since

$$I = \frac{E}{Z}$$

then

$$I = \frac{208\underline{/0^\circ}}{100\underline{/53.1^\circ}}$$

$$= 2.08\underline{/-53.1^\circ}. \qquad \text{(B)}$$

The phase angle has already been determined (-53.1°). (C)

Determination of Power

Power in a-c circuits may be calculated in much the same basic manner as in d-c circuits. That is, the basic mathematical relations still apply, in that $P = I \times E$, or that $P = I^2 \times Z$. The necessary inclusion of phase angle or power factor considerations is automatically accomplished by the use of rectangular notation. Since the voltages, currents, and impedances involved in power calculations are already divided into their energy and reactive components, then the solution of these calculations will yield an answer which is also divided into its energy and reactive components. That is, it will state the magnitude of both true power and VARS.

Before attempting power calculations, you should fix the following rule firmly in mind: When multiplying a voltage and current, YOU MUST USE THE CONJUGATE OF THE VOLTAGE to obtain a correct answer. To obtain

the conjugate of a rectangular vector, reverse the sign of the j operator. To obtain the conjugate of a polar vector, reverse the sign of the indicated angle. By using the conjugate of voltage, the algebraic sign of the j operator in the result will be of the proper type. That is, the power vector for an inductive circuit will have a $-j$, and a capacitive circuit will have a $+j$. This will be demonstrated during the following calculations.

For the circuit shown in figure 3-12, determine the following: (A) impedance, (B) voltage, (C) phase angle, (D) power factor, (E) true power, (F) VARS, and (G) apparent power.

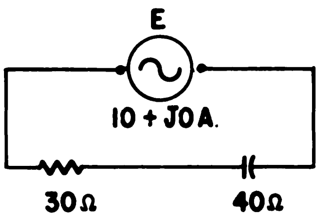


Figure 3-12.—Series circuit for power calculation.

Impedance is $30 - j40\,\Omega$. (A)

Since $E = I \times Z$

then $E = (10 + j0) \times (30 - j40)$

$= 300 - j400$ volts. (B)

$$\tan\theta = \frac{-j400}{300}$$

$= -1.33 =$ tangent of $-53.1°$. (C)

power factor $= \cos\theta \times 100$

$= (0.600 \times 100)$

$= 60\%$. (D)

power is $P = E \times I$

$= (300 - j400) \times (10 + j0)$

$= 3{,}000 + j4{,}000$ VA.

Therefore, true power = 3,000 watts. (E)

$$\text{VARS} = j4{,}000 \text{ VA.} \tag{F}$$

apparent power (or total volt-amperes) =

$$\frac{\text{true power}}{\cos 53.1^\circ} \text{ or } \frac{\text{VARS}}{\sin 53.1^\circ}. \tag{G}$$

In either case, it is 5,000 VA. Note that reversal of the sign of the j operator in the voltage vector caused the sign of the j operator in the power vector to be plus. This is as it should be, since the circuit is capacitive. Had voltage and current been converted to polar form for multiplication, it still would have been necessary to conjugate the voltage. The rectangular voltage $300 - j400$ converted to polar form would have been $500\underline{/-53.1^\circ}$ volts. Before multiplication it would have been conjugated to $500\underline{/53.1^\circ}$ volts. The solution for power would then have been $500\underline{/53.1^\circ}$ volts × $10\underline{/0^\circ}$ amps = $5{,}000\underline{/53.1^\circ}$ VA. Note that $5{,}000\underline{/53.1^\circ}$ VA. is the correct polar form of $3{,}000 + j4{,}000$ VA.

Solution of Parallel Circuits

The mathematical relations and processes involved in the solution of a-c parallel circuits are identical in operation to those for d-c parallel circuits. The quantities are merely more complex. In d-c parallel circuits, total current is found by first determining and then combining all branch currents ($I_T = I_1 + I_2 + I_3$, etc.). Also, total resistance is found by combining the reciprocals of all branch resistances, and then determining the reciprocal of this combined quantity.

$$\left(R_T = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)} \right).$$

However, in a-c circuits, current will be given and used in complex form, and impedance (Z) will be given and used instead of resistance.

The circuit in figure 3-13 will be solved by determining currents first.

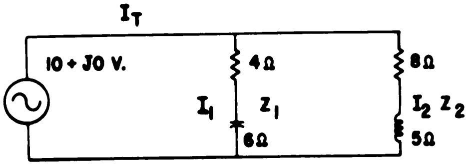


Figure 3-13.—Parallel circuit for solution by currents.

$$I = \frac{E}{Z} \text{ in a-c.}$$

Then

$$I_1 = \frac{10 + J0}{4 - J6}$$

$$= \frac{10 + J0}{4 - J6} \times \frac{4 + J6}{4 + J6}$$

$$= \frac{40 + J60}{52}$$

$$= 0.77 + J1.15 \text{ amp.}$$

$$I_2 = \frac{10 + J0}{8 + J5}$$

$$= \frac{10 + J0}{8 + J5} \times \frac{8 - J5}{8 - J5}$$

$$= \frac{80 - J50}{89}$$

$$= 0.9 - J.56 \text{ amp.}$$

Since

$$I_T = I_1 + I_2$$

then

$$I_T = (0.77 + J1.15) + (0.9 - J.56)$$

$$= 1.67 + J.59 \text{ amps.}$$

With line voltage and total current known, circuit impedance may be determined.

$$Z_T = \frac{E}{I_T}$$

$$Z_T = \frac{10+j0}{1.67+j.59}$$

$$= \frac{10+j0}{1.67+j.59} \times \frac{1.67-j.59}{1.67-j.59}$$

$$= \frac{16.7-j5.9}{3.13}$$

$$= 5.34-j1.88\,\Omega.$$

There would be little point in representing I_1 and I_2 in polar form, since they could not be combined in that form to obtain I_T. However, the division of voltage by impedance might have been facilitated by first converting these quantities to polar form, since polar vectors are more easily divided than rectangular vectors. On the other hand, some time is required for this conversion. Consequently, the question of whether to convert or not depends on how well you are able to perform the conversion. You should use the quickest or most convenient method.

In the majority of cases, solution of parallel circuits by currents is the most feasible method. However, some problems require the determination of total impedance, and voltage is not given. In such cases, where neither voltage nor any branch current is known, I_T, or total current, cannot be determined. The circuit could be solved only to the extent of determining total impedance. This is done in a-c circuits by use of the same basic method used in d-c circuits. Where total resistance in d-c circuits is

$$R_T = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}},$$

total impedance in a-c circuits is

$$Z_T = \frac{1}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_3}}.$$

When ONLY TWO BRANCHES are considered in d.c.,

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}.$$

Likewise in a-c circuits, total impedance is

$$Z_T = \frac{Z_1 \times Z_2}{Z_1 + Z_2}.$$

If feasible, the reciprocal formula may also be used when solving two impedances.

Figure 3-13 will be solved for total impedance using both methods mentioned. The reciprocal formula will be used first, assuming that line voltage is not given.

$$Z_T = \frac{1}{\frac{1}{Z_1} + \frac{1}{Z_2}}$$

The reciprocal of each branch impedance must first be determined.

$$\frac{1}{Z_1} = \frac{1}{4 - j6}$$

$$= \frac{1}{4 - j6} \times \frac{4 + j6}{4 + j6}$$

$$= \frac{4 + j6}{52}$$

$$= 0.077 + j.115.$$

$$\frac{1}{Z_2} = \frac{1}{8 + j5}$$

$$= \frac{1}{8 + j5} \times \frac{8 - j5}{8 - j5}$$

$$= \frac{8 - j5}{89}$$

$$= 0.089 - j.056.$$

Combining reciprocals

$$\frac{1}{Z_1} + \frac{1}{Z_2} = (0.077 + j.115) + (0.089 - j.056)$$

$$= 0.166 + j.059.$$

Total impedance is

$$Z_T = \frac{1}{0.166 + j.059}$$

$$= \frac{1}{0.166 + j.059} \times \frac{0.166 - j.059}{0.166 - j.059}$$

$$= \frac{0.166 - j.059}{0.031}$$

$$= 5.34 - j1.88\,\Omega.$$

Since only two branches are involved, the second method of solution may also be used. Starting with the formula

$$Z_T = \frac{Z_1 \times Z_2}{Z_1 + Z_2},$$

then

$$Z_T = \frac{(4 - j6) \times (8 + j5)}{(4 - j6) + (8 + j5)}.$$

The numerator is $(4 - j6) \times (8 + j5) = 32 - j28 - j^2 30 = 62 - j28$. The denominator is $(4 - j6) + (8 + j5) = 12 - j1$. Divide the numerator by the denominator as follows:

$$Z_T = \frac{62 - j28}{12 - j1}$$

$$= \frac{62 - j28}{12 - j1} \times \frac{12 + j1}{12 + j1}$$

$$= \frac{772 - j274}{145}$$

$$= 5.34 - j1.88\,\Omega.$$

The impedance of the circuit has thus been solved in each of three ways: (1) by currents, (2) by the reciprocal formula, and (3) by the last method shown.

Solution of Series — Parallel Circuits

SOLUTION IN RECTANGULAR FORM.—The circuit shown in figure 3-14 will be solved during the following explanation. Total current I_T, branch currents I_2 and I_3, total impedance, voltages E_1 and E_2, power, and phase angle will be determined.

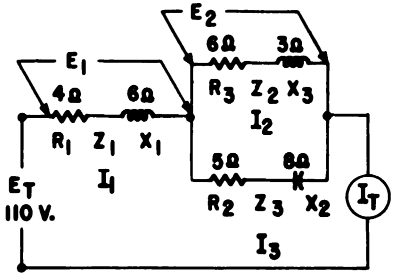


Figure 3-14.—Series–parallel circuit.

To obtain total current, total impedance must first be determined. Total impedance is $Z_T = Z_1 + (Z_2 \oplus Z_3)$, so the solution of $(Z_2 \oplus Z_3)$ must be carried out first. The formula for two parallel impedances will be used.

$$Z_2 + Z_3 = \frac{Z_2 \times Z_3}{Z_2 + Z_3}.$$

The numerator $Z_2 \times Z_3$ is $(6+j3) \times (5-j8) = 54-j33$. The denominator is $Z_2 + Z_3$, or $(6+j3) + (5-j8) = 11-j5$.

Insert these quantities in the formula for parallel impedance,

$$\begin{aligned} Z_2 \oplus Z_3 &= \frac{54-j33}{11-j5} \\ &= \frac{54-j33}{11-j5} \times \frac{11+j5}{11+j5} \\ &= \frac{759-j93}{146} \\ &= 5.2-j.64\,\Omega. \end{aligned}$$

Adding $(5.2 - j.64\Omega)$ to Z_1 $(4 + j6\Omega)$, total impedance Z_T is obtained

$$Z_T = (5.2 - j.64) + (4 + j6)$$
$$= 9.2 + j5.36\Omega.$$

Now that total impedance is known, and total voltage is given, total current I_T may be determined by the formula

$$I_T = \frac{E_T}{Z_T}.$$

Insert the known values for E_T and Z_T; then

$$I_T = \frac{110 + j0}{9.2 + j5.36}$$

$$= \frac{110 + j0}{9.2 + j5.36} \times \frac{9.2 - j5.36}{9.2 - j5.36}$$

$$= \frac{1{,}012 - j589}{113.4}$$

$$= 8.92 - j5.19 \text{ amps.}$$

Since the total current must flow through the series impedance Z_1, then the voltage E_1 may now be determined. $E_1 = Z_1 \times I_T$, or $(4 + j6) \times (8.92 - j5.19)$. $E_1 =$ 66.8+ 32.6 volts. With E_1 known, E_2 is easily determined, because E_2 must equal E_T minus E_1. $E_2 = E_T - E_1 = (110 + j0) - (66.8 + j32.6) = 43.2 - j32.6$ volts. E_2 is the same across both parallel impedances Z_2 and Z_3, so the current through each may now be determined.

$$I_2 = \frac{E_2}{Z_2}$$

$$= \frac{42.2 - j32.6}{6 + j3}$$

$$= \frac{43.2 - j32.6}{6 + j3} \times \frac{6 - j3}{6 - j3}$$

$$= \frac{161.3 - j325}{45}$$

$$= 3.59 - j7.23 \text{ amps.}$$

$$I_3 = \frac{E_2}{Z_3}$$

$$= \frac{43.2 - j32.6}{5 - j8}$$

$$= \frac{42.2 - j32.6}{5 - j8} \times \frac{5 + j8}{5 + j8}$$

$$= \frac{474.37 + j181.56}{89}$$

$$= 5.33 + j2.04 \text{ amps.}$$

At this point, the solutions for voltages and currents may be checked before performing power calculations. To check, $E_1 + E_2$ should equal E_T; that is, $(66.8 + j32.6) + (43.2 - j32.6) = 110 + j0$ volts. Also, $I_2 + I_3$ should equal I_1, or I_T; that is $(3.59 - j7.23) + (5.33 + j2.04) = 8.92 - j5.19$ amps.

The power for the entire circuit is $P = E_T \times I_T$. That is, $P = (110 + j0) \times (8.92 - j5.19)$ VA. $E_T \times I_T = 980 - j572$ volt-amperes, which indicates a true power of 980 watts, and reactive volt-amperes of 572 VARS.

To solve for the phase angle θ, the tangent of θ is $j572/980$, or 0.583. This is the tangent of 30.2°, which is the phase angle for the entire circuit. The cosine of 30.2° is 0.8643. This, when multiplied by 100, yields a power factor of 86.43%.

SOLUTION IN POLAR FORM.—The solution for currents and voltages in figure 3-14 can also be performed by the use of polar quantities. To do this, the first step is to convert all rectangular quantities to their polar form. At the same time, you must retain the rectangular quantities, because total impedance must be determined first, and rectangular quantities must be used to do this. Rectangular quantities will also have to be used in various other processes, as you will see during the course of solution.

Total impedance Z_T was determined to be $9.2 + j5.36\,\Omega$, and E_T is given as $110 + j0$ volts. If polar form is to be used for solving total current I_T, then E_T and Z_T must be converted to polar form. Z_T is converted as follows:

$$\frac{j5.36}{9.2} = \tan\theta$$

$$= \tan 30.2°.$$

The polar angle of Z_T is 30.2°. Then the polar magnitude of Z_T is

$$\frac{j5.36}{\sin 30.2°} \quad \text{or} \quad \frac{9.2}{\cos 30.2°}.$$

Either method you prefer may be used. In either case, its magnitude is 10.65. The complete polar form of Z_T is $10.65\underline{/30.2°}\ \Omega$. E_T in polar form is 110/0° volts. Total current is

$$I_T = \frac{E_T}{Z_T}$$

$$= \frac{110\underline{/0°}}{10.65\underline{/30.2°}}.$$

By dividing magnitudes and subtracting angles, I_T is determined to be $10.32\underline{/-30.2°}$ amps.

The next quantity to be determined is E_1. If this is done in polar form, Z_1 must first be converted to polar form before multiplying by I_T. The tangent of angle θ for Z_1 is $j6/4$, or 1.5, the tangent of 56.3°.

Determining the polar magnitude

$$Z_1 = \frac{j6}{\sin 56.3°}, \text{ or}$$

$$= \frac{4}{\cos 56.3°}$$

$$Z_1 = 7.2$$

$$Z_1 = 7.2\underline{/56.3°}\ \Omega$$

$$E_1 = Z_1 \times I_T$$

$$= 7.2\underline{/56.3°} \times 10.32\underline{/-30.2°}.$$

Multiplying magnitudes,

$$(7.2) \times (10.32) = 74.3,$$

combining angles

$$(56.3°) + (-30.2) = 26.1°$$

then,

$$E_1 = 74.3\underline{/26.1°} \text{ volts.}$$

To determine E_2, E_1 is subtracted from E_T. Since polar quantities cannot be subtracted algebraically, E_T and E_1 are reconverted to rectangular form. The rectangular forms of E_T and E_1 have already been determined. Their difference is E_2. E_2 was determined to be 43.2 - j32.6 volts. If I_2 is to be expressed in polar form, then E_2 and Z_2 must first be converted to polar form, since I_2 is E_2/Z_2. The same applies to the solution for I_3. That is, Z_3 would also have to be converted to polar form, because I_3 is E_2/Z_3.

The calculation for power and phase angle is relatively simple, since the polar forms of E_T and I_T are known, and can be multiplied in that form

$$(P = E_T \times I_T \text{ VA.}).$$

Solving for power:

$$(110\underline{/0°}) \times 10.32\underline{/-30.2°}) = 1{,}133\underline{/-30.2°} \text{ VA.}$$

This indicated quantity may be checked against the indicated rectangular quantity 980 - j572 VA. as follows:

$$1{,}133 \times \cos -30.2° = (1{,}133) \times (0.866)$$
$$= 980 \text{ watts.}$$

Also,

$$1{,}133 \times \sin -30.2° = (1{,}133) \times (0.503)$$
$$= -j572 \text{ VARS.}$$

It will be noted that the use of polar vectors to solve the circuit in figure 3-14 required frequent conversion of polar vectors to rectangular vectors. These conversions were necessary due to the difficulty in adding or subtracting quantities expressed in polar form, and considerable time and effort is needed for these conversions. Consequently, it will usually be to your advantage to employ rectangular quantities, rather than polar quantities, since the rectangular form is not subject to any such mathematical limitation.

QUIZ

1. Vectors in polar form may be
   a. multiplied or added
   b. divided or subtracted
   c. added or subtracted
   d. multiplied or divided.

2. To add vectors given in polar form, you must
   a. add their magnitudes and subtract their angles
   b. add their magnitudes and add their angles
   c. convert them to rectangular form and combine algebraically
   d. convert them to rectangular form and subtract algebraically.

3. When representing a-c quantities with rectangular vectors,
   a. inductive impedances and inductive voltage drops will have a $+J$
   b. inductive impedances and inductive currents will have a $+J$
   c. capacitive currents and capacitive impedances will have a $+J$
   d. capacitive impedances and capacitive voltages will have a $-J$.

4. If the rectangular vector $30 + J40$ VA represents the apparent power in a given circuit,
   a. there is 40 watts of true power
   b. the circuit is capacitive
   c. the circuit is inductive
   d. the power factor is 100 percent.

5. If a resistance, inductive reactance, and capacitive reactance, each unequal to the other, are connected first in series and then in parallel,
   a. total impedance is the same in either case
   b. the power factor is the same in either case
   c. current would lead in the series connection and lag in the parallel connection
   d. total impedance will depend on the type of connection.
6. A wattmeter
   a. will give a positive indication for an inductive circuit and a negative indication for a capacitive circuit
   b. indicates line volt-amperes at all times
   c. cannot normally differentiate between capacitive and inductive loads
   d. is essentially a series voltage coil and parallel amperage coil acting on a common meter movement.
7. The load rating of an a-c generator or inverter is determined by
   a. the amount of internal heat it can withstand
   b. the power factor of its load
   c. its power rating in watts
   d. multiplying full-load current by no-load voltage.
8. The internal heating of an a-c generator or inverter is
   a. caused by energy current only
   b. caused by reactive current only
   c. maximum when the load power factor is 100 percent
   d. caused by any current, regardless of its nature, that flows through its armature.
9. An a-c generator's output voltage is connected in parallel to a resistance *R*, and an inductive reactance *XL*. A capacitive reactance *XC* is then also connected in parallel. If *XC* is equal to *XL*,
   a. reactive current through the generator will be maximum after *XC* is connected
   b. circulating current between the capacitance and inductance will be maximum
   c. the line phase angle will increase
   d. true power will decrease.
10. The rectangular description of a vector
    a. will state its horizontal component first
    b. does not include any indication of the vector's direction
    c. refers to a vector's length in relation to the length of one side of an imaginary rectangle
    d. will always state its vertical component first.

11. The polar vector $50\underline{/-53.1°}$, when converted to its rectangular form, is
    a. $50 - J53.1$
    b. $40 - J30$
    c. $30 - J40$
    d. $30 + J40$
12. When the rectangular quantity $100 + J100$ is converted to its polar form, it is
    a. $14.14\underline{/45°}$
    b. $141.4\underline{/-45°}$
    c. $141.4\underline{/45°}$
    d. $14.14\underline{/-45°}$.
13. The conjugate of a rectangular quantity is
    a. the same quantity, but with the sign of its J factor reversed
    b. the square of the quantity
    c. the same as its polar form
    d. involved only in multiplying that quantity by another of the same type.
14. If an impedance is represented as $20+J15$,
    a. it might consist of a resistance of 20 ohms in parallel with an inductive reactance of 15 ohms
    b. line voltage will lag line current when power is connected to this impedance
    c. the impedance is inductive
    d. line phase angle would increase if another impedance of $0 - J15$ ohms were connected in series.
15. When consulting the table of trigonometric functions, a sine value of 0.6428, a cosine value of 0.500, and a tangent value of 5.6713 are each located in that order. The indicated number of degrees for each value is
    a. 40°, 45°, 50°
    b. 30°, 32°, 34°
    c. 40°, 40°, 40°
    d. 40°, 60°, 80°.
16. Two rectangular vectors have been multiplied, and their product has been solved to the form of $25 + J10 - J^2 20$. Their final product will be
    a. $5 + J10$
    b. $25 - J10$
    c. $25 + J30$
    d. $45 + J10$.
17. The tangent of the angle implied by the vector expression $40 - J20$ is
    a. 2
    b. 0.2
    c. 5
    d. 0.5.

18. When multiplying a voltage by a current, in either polar or rectangular form, to obtain power, the
    a. energy component of the voltage is multiplied only by the energy component of the current
    b. conjugate of the voltage must be used
    c. problem cannot be worked without reference to the table of trigonometric functions
    d. answer will indicate total apparent power without further solution by trigonometry.
19. When pairing a-c quantities, represented by rectangular vectors, according to the algebraic signs of their *J* factors, you would group
    a. an inductive impedance with a capacitive voltage, and a capacitive impedance with an inductive voltage
    b. the power in a capacitive circuit with the impedance of an inductive circuit, and the power in an inductive circuit with the current in a capacitive circuit
    c. the current in an inductive circuit with the impedance of an inductive circuit, and the current in a capacitive circuit with the impedance of a capacitive circuit
    d. the current and power of a capacitive circuit together, and the impedance and voltage of an inductive circuit together.
20. When deciding whether to convert vector quantities from one form to another, you should remember that polar vectors are easier to
    a. add or subtract, and rectangular vectors are easier to multiply or divide
    b. subtract or multiply, and rectangular vectors are easier to divide or add
    c. multiply or divide, and rectangular vectors are easier to add or subtract
    d. add or divide, and rectangular vectors are easier to subtract or multiply.

CHAPTER 4

ADVANCED ALTERNATING-CURRENT THEORY — CONTINUED

INTRODUCTION TO POLYPHASE POWER SYSTEMS

Advantages of Polyphase Systems

In recent years, the a-c power systems in naval aircraft have assumed ever greater importance as part of the aircraft's functioning equipment. The trend in electrical power systems is away from direct-current systems and toward alternating-current systems. More specifically, the trend is almost entirely toward polyphase a-c systems for the generation and distribution of electrical power.

The weight-to-performance ratio is of prime importance in the design of all airborne equipment, and this applies to electrical power components as well. This fact has a direct bearing on the reasons for using polyphase systems instead of single-phase systems. A three-phase a-c generator or inverter of given weight and dimensions may have up to a 60 percent greater power rating than a single-phase machine of the same physical size and weight. This same approximate power rating applies also to a-c motors.

Another important consideration is the conductor weight of the distribution system. To conduct equal amounts of power, the three-phase system requires only

about 75 percent of the copper weight which would be required for a single-phase system.

Also, the pulsating load on a single-phase a-c generator is reflected in continuous pulsations of the mechanical drive shaft speed and torque. In a three-phase generator, individual phase power is pulsating, but the total power of all three phases is constant if the load is balanced. Consequently, the generator drive shaft speed and torque are constant.

Double Subscript Notation

In working with problems which involve more than one voltage or current, it is best to employ a systematic means of identification for referring to these voltages and currents. One method for doing this is the use of letters used as subscripts. For instance, the currents in a parallel circuit of three branches might be referred to as I_A, I_B, and I_C. By using a double subscript (two letters), direction as well as identity may be established for a quantity. Suppose the three parallel branches mentioned are connected to a common bus, or point, identified as point O. The three currents, if they were all flowing toward point O, could then be referred to as I_{AO}, I_{BO}, and I_{CO}. Conversely, if all currents were flowing away from point O, then a reversal of direction would be indicated by reversing the currents' subscripts. In this case, they would be I_{OA}, I_{OB}, and I_{OC}.

This system of notation may be applied equally well to voltages, since voltage is assumed to act in a certain direction. As with current, the direction of a voltage may be indicated by the sequence of its subscript.

When voltages or currents are represented in equations, their algebraic direction may be represented by the sequence of their subscripts as well as their algebraic sign. This relation will be shown by referring to the voltages in the circuit shown in figure 4-1 (A).

Total circuit voltage E_{AD} is obviously comprised of the segment voltages E_{AB}, E_{BC}, and E_{CD}. This fact could thus be stated in the form of an equation as follows:

$$E_{AD} = E_{AB} \oplus E_{BC} \oplus E_{CD} .$$

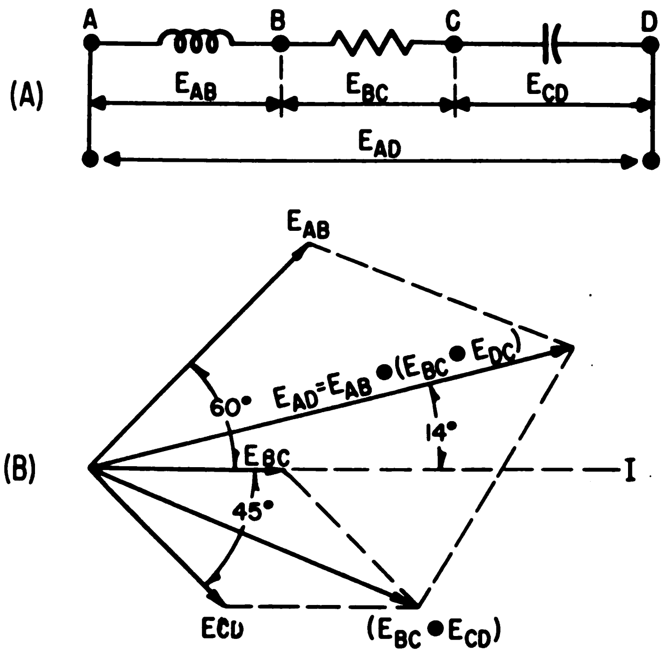


Figure 4-1.—(A) Circuit segment voltages; (B) segment voltage vectors.

(Since the segment voltages are vector quantities, they must be added as vectors.) Assume the segment voltages have individual phase angles as shown in part (B) of figure 4-1. Part (B) also shows how the successive combining of vectors produced E_{AD}. Note that all vectors are acting in an A toward D direction.

Since E_{AD} is composed of the segment voltages shown, it follows that E_{AD} minus all segment voltages would equal zero. In equation form, after transposing and changing the signs of the segment voltages, E_{AD} is equated to zero as follows:

$$E_{AD} \oplus (-E_{AB}) \oplus (-E_{BC}) \oplus (-E_{CD}) = 0 .$$

(It must be remembered that to subtract vectors, one vector is reversed, and then the two are added.) Since all segment voltage vectors are to be subtracted from E_{AD}, all of them are reversed. By reversing subscripts

the equation $E_{AD} \oplus (-E_{AB}) \oplus (-E_{BC}) \oplus (-E_{CD}) = 0$ can be simplified as follows: $E_{AD} \oplus E_{BA} \oplus E_{CB} \oplus E_{DC} = 0$. To prove this equation correct, the successive vector subtraction of segment voltages from E_{AD}, as indicated in the equation, is carried out in figure 4-2.

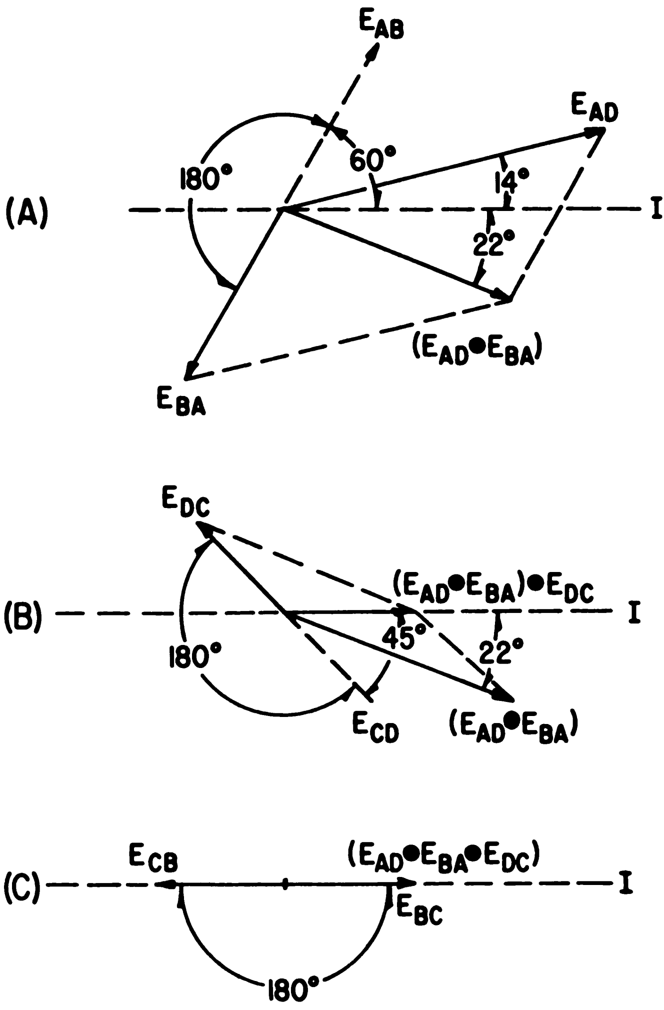


Figure 4-2.—Subtraction of voltage vectors.

In part (A), E_{AB} is reversed to E_{BA} and added to E_{AD}, obtaining $E_{AD} \oplus E_{BA}$. In part (B), E_{CD} is reversed to E_{DC} and added to $(E_{AD} \oplus E_{BA})$, obtaining $(E_{AD} \oplus E_{BA} \oplus E_{DC})$. Note in part (C) that this quantity lies exactly along E_{BC}, so that when E_{BC} is reversed to E_{CB}, the result is zero. This proves, by direct vector analysis, that showing vector directions by subscripts is a method of representation which is both accurate and simple, when these vectors appear in mathematical equations. The use of double-subscript notation is particularly effective in separating and identifying polyphase voltages and currents when these quantities are represented as vectors.

Generation of Polyphase Voltages

The three-phase a-c power system is by far the most commonly used of any polyphase system. For this reason, only the three-phase system will be discussed in this chapter.

Alternating-current generators and inverters are manufactured in a variety of sizes, shapes, and ratings. These vary in appearance and performance from tiny synchro signal generators to the relatively huge a-c generators installed aboard certain large patrol-type aircraft. However, practically all these machines have some features in common. They usually have a rotating field of fixed polarity and a stationary armature. No matter what the size or complexity of these machines, they may be simplified for purposes of explanation to the forms shown in figure 4-3.

The field is reduced to a simple rotary two-pole magnet, and the armature windings are reduced to three simple coils fixed 120 electrical degrees apart. Note that dashed lines extend end-to-end through the field and all three coils. The dashed lines through the coils will be referred to as "coil planes," and the dashed line through the field will be referred to as the "field plane." The coils are labeled A, B, and C, and corresponding coil ends are connected to form a common reference point labeled O. It is assumed that the coils are wound so that when the north field pole is adjacent to any coil, the direction of induced voltage is AWAY from point O and TOWARD the lettered end of that coil. This voltage direction will

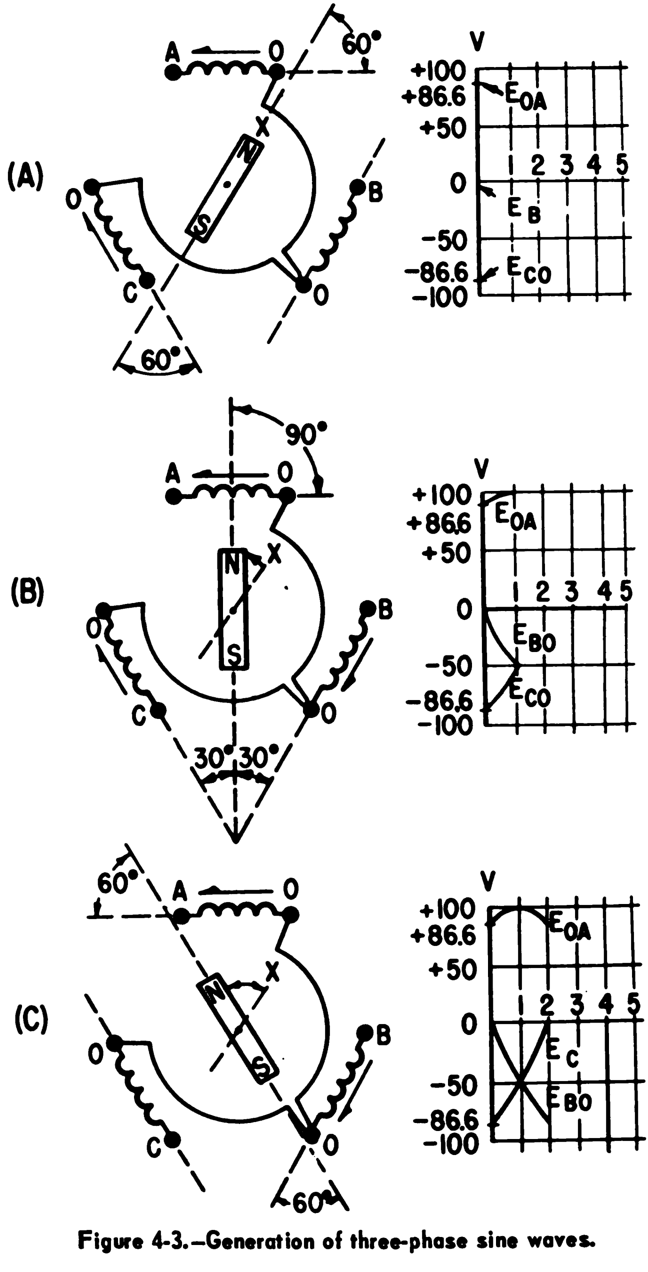


Figure 4-3.—Generation of three-phase sine waves.

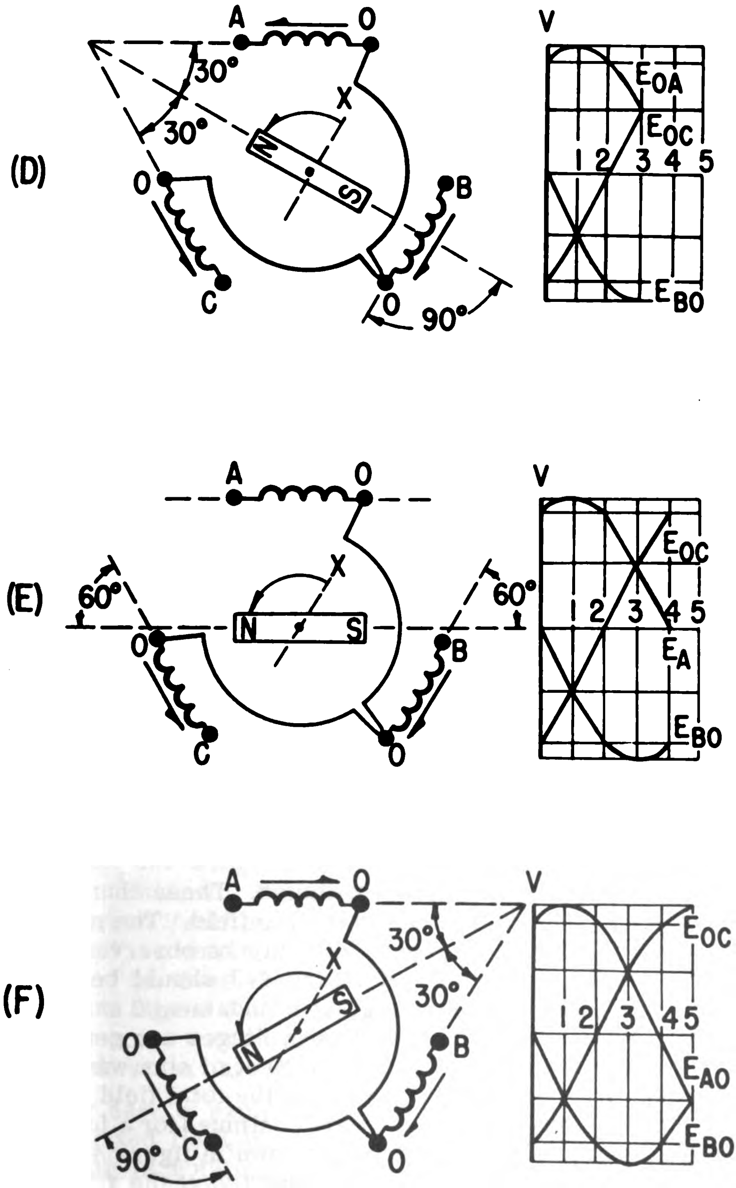


Figure 4-3.—Generation of three-phase sine waves—Continued.

be referred to as "positive." A positive voltage may thus be identified by the order of its subscript (E_{OA}, E_{OB}, or E_{OC}). It follows that when the south field pole is adjacent to any coil, the direction of induced voltage is "negative"; that is, from the lettered end toward the common end. Again, the direction is indicated by the order of subscripts. Negative voltage would be E_{AO}, E_{BO}, or E_{CO}. Peak voltage in the coils is 100 volts.

At the starting instant shown in part (A) of figure 4-3, the field plane lies along an axis labeled X. At this instant, it can be seen that the field plane is at 60° to the plane of coil A. Consequently, the instantaneous voltage in coil A is 100 × sin 60° = 100 × 0.866 = 86.6 volts. The north field pole is adjacent to coil A, so its induced voltage is positive. This value is indicated as +86.6 (E_{OA}) on the sine graph to the right of the drawing. The plane of coil B is parallel (0°) to the field plane, so its voltage is zero. Coil C is at 60°, but adjacent to the south field pole, so its instantaneous voltage (E_{CO}) is negative, -86.6 volts, as shown on the sine graph.

In part (B) of figure 4-3, the field has been rotated 30° away from the X axis. It can be seen that all three coil voltages have undergone simultaneous changes, in accordance with the changes of their coil plane angles with respect to the field. These changes are traced as the beginnings of sine waves on the graph. E_{OA} increased from 86.6 volts to 100 volts. E_B started in a negative direction, becoming E_{BO}, and increased to -50 volts. E_{CO} decreased from -86.6 volts to -50 volts.

Parts (C), (D), (E), and (F) of figure 4-3 show successive changes in the coil voltages. These changes are caused by additional rotation of the field. The progressive development of sine waves may be observed on the sine graphs. All parts of figure 4-3 should be studied carefully, since it illustrates the fundamental manner in which practically all three-phase voltages are generated.

Figure 4-3 traces the development of sine waves only through five steps of 30° each, for the total field rotation of 150°. If the development were continued for a full 360°, the sine graph would appear as shown in figure 4-4.

Where the field in figure 4-3 started at the X axis and rotated 150°, the same field as represented by arrows is considered to have rotated 360° when shown in figure 4-4

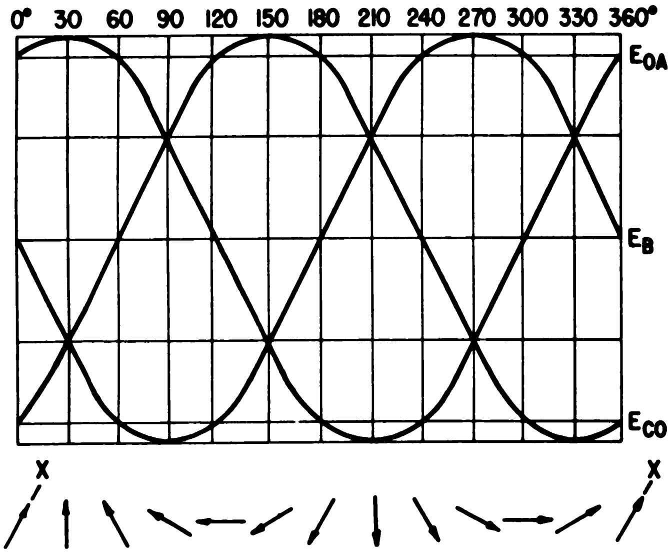


Figure 4-4.—360° development of three-phase sine wave.

Vectors of Three-Phase Voltage

The methods used in figures 4-3 and 4-4 suffice to show how three-phase voltages are generated and their sine waves are formed. Also, the instantaneous magnitude and direction of any phase voltage, for a given field position, is easily determined by observing the sine graph. However, the drawing and construction of the sine graph itself is a laborious process. A more practical and convenient method for representing three-phase voltages involves the use of rotating vectors of the type shown in figure 4-5 (A). Note that these vectors are laid out in such a way as to coincide with the three coil positions shown in part (B).

For ease of explanation, the a-c generator in part (B) has a fixed field and rotary coils. Regardless of which member is rotating, instantaneous coil voltage is still determined by the angle between field plane and coil plane. Any coil lying to the right of the *X* axis will have a

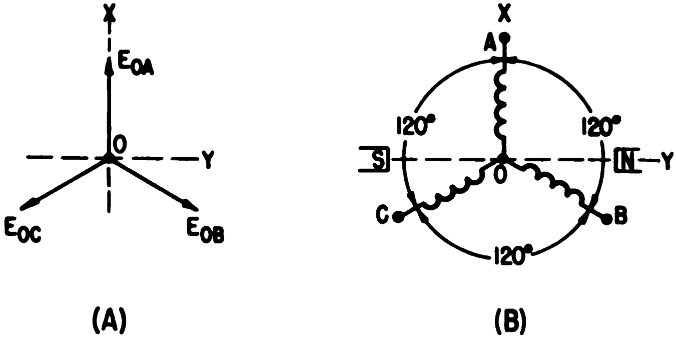


Figure 4-5.—(A) Three-phase vector; (B) corresponding coil positions.

positive direction of induced voltage, or AWAY from terminal O. A coil lying to the left would have a negative voltage. Peak voltage in a coil would exist when it lay exactly along the Y axis (peak positive to the right, and peak negative the left). If the peak value of coil e. m. f.'s were represented by the length of the rotary vectors in part (A), then INSTANTANEOUS voltage direction could be determined by observing on which side of the X axis a particular vector is lying. Further, in addition to direction, its instantaneous magnitude is determined by the angle (θ) between the vector and the Y axis. That is, $e = E \times \sin \theta$, where e is instantaneous voltage, E is peak voltage, and θ is the instantaneous angle between a particular vector and the Y axis.

In addition to determining individual phase voltages, vectors may also be used to determine the voltage between two conductors, where each conductor is connected to a different phase coil. Figure 4-6 will be used to demonstrate that this voltage (line-to-line voltage) is the DIFFERENCE of the phase coil voltages. To obtain line-to-line voltage from two such coils, the leading phase is subtracted algebraically from the lagging phase. In figure 4-6 (A), assuming a CCW rotation, coil B leads coil A. (Coil C is disregarded, since it contributes nothing to E_{AB}.) The line-to-line voltage must be $E_{AO} - E_{OB}$ or -86.6 - (+86.6). Dropping the parenthesis and changing the sign within, E_{AB} = -86.6 - 86.6 = -173.2 volts.

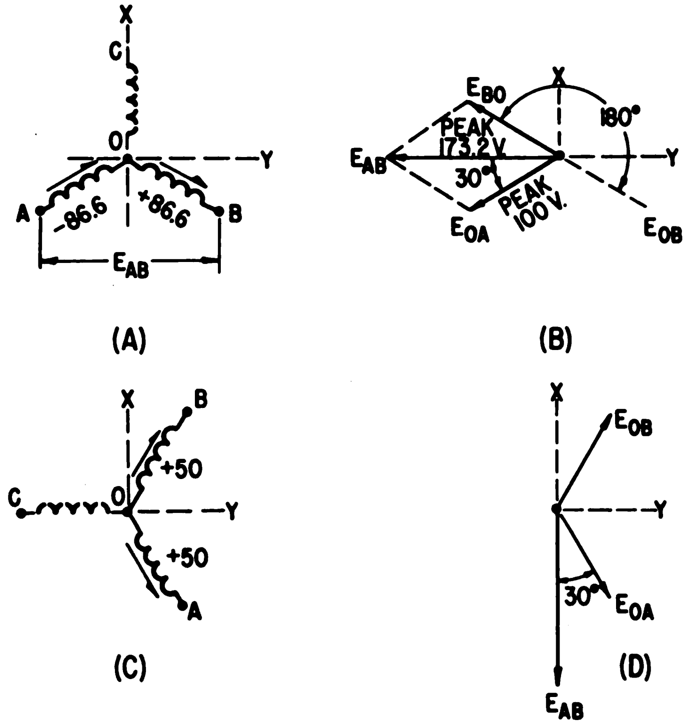


Figure 4-6.—Combining polyphase voltages by vectors.

WYE-CONNECTED SYSTEMS

Voltages in a Wye-Connected System

The wye connection for a three-phase system is one in which an end of each phase is connected to a common junction. It is probably apparent by now that this type of connection affects system voltages in ways peculiar to itself.

If the same operation were carried out vectorially, the usual rules for subtracting vectors would apply. Referring to figure 4-6 (B), vector E_{OB} is leading, and is therefore the subtrahend. To subtract E_{OB} from E_{OA}, E_{OB} is reversed 180° as shown, and then added to E_{OA}. The result is E_{AB}. Note that E_{AB} lies exactly along the Y axis,

and is also to the left of the X axis. This means that at the instant shown in both (A) and (B), the line-to-line voltage is at its negative peak value. If vectors E_{OA} and E_{OB} are considered to be 100 units long, then E_{AB} is 173.2 units long. That is, the peak value of line-to-line voltage E_{AB} is 173.2 volts. Part (A) and (B) are thus seen to be in complete agreement.

In part (C) of figure 4-6, the coils have been rotated so that both lie to the right of the X axis, and are equal distances from the Y axis.

Consequently, both have positive and equal voltages. In this case, E_{AB} is obviously zero. This is proven as follows: $E_{AB} = +50 - (+50) = +50 - 50 = 0$ volts. This agrees with the vector representation as shown in part (D). Note that vector E_{AB} lies exactly along the X axis, indicating a magnitude of zero.

Figure 4-7 depicts a four-wire, three-phase system of the type most commonly used in naval aircraft. In addition to the three-phase conductors, a fourth conductor is brought out from the common junction. This conductor is most commonly referred to as "neutral." Voltage V_2 in figure 4-7 (A) is taken between the phase-line (A) and neutral. This is known as "line-to-neutral" voltage, and is obviously equal only to the voltage of the phase across which it is taken. Voltage V_1 is a "line-to-line" voltage. As shown in (B) of figure 4-6, the line-to-line voltage of two coils 120° apart is equal to EITHER coil's voltage times 1.73. It can be stated that in figure 4-7 $V_1 = V_2$ or $V_3 \times 1.73$ ($1.73 = \sqrt{3}$). This relation is true for all wye-connected three-phase systems under balanced load conditions. That is, line voltage E_L is equal to coil (phase) voltage E_c times $\sqrt{3}$ or ($E_L = E_C \times 1.73$). This is true, using either effective coil voltage or peak coil voltage. However, the resultant line voltage will also be of corresponding effective or peak value. Conversely, if line voltage E_L is known, coil voltage is:

$$E_C = \frac{E_L}{1.73}.$$

An additional characteristic of wye voltages is shown in (B) of figure 4-7. It can be seen that any line-to-line voltage lags one of its phase voltages by 30° and the other

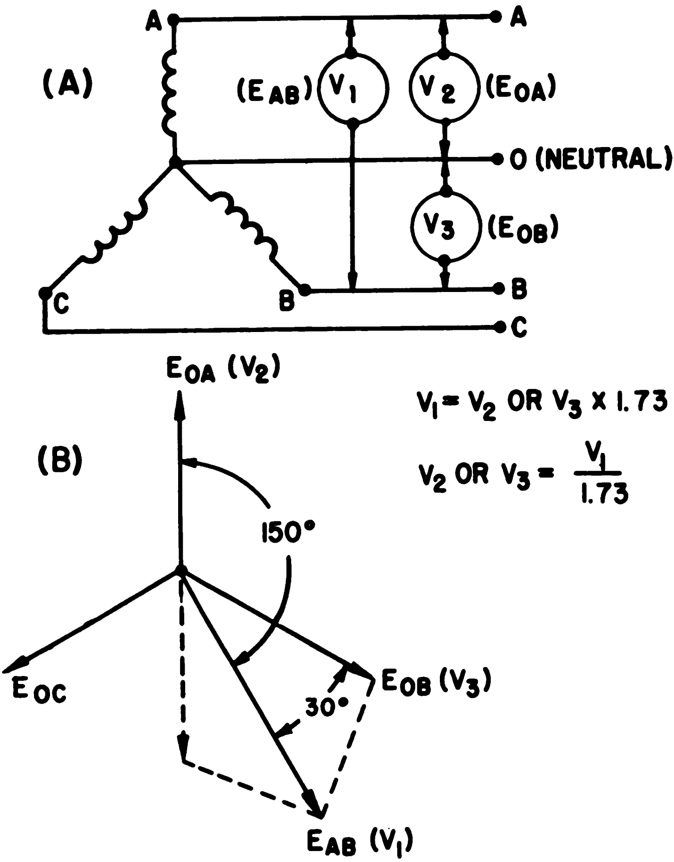


Figure 4-7.—Voltages in wye-connected three-phase system.

phase voltage by 150°. This would be true for any two combined phase voltages, such as the combining of V_2 and V_3 to produce V_1.

Currents in Wye-Connected Systems

Figure 4-8 (A) shows a wye-connected three-phase generator supplying a balanced load. Each load resistor is 100 ohms, and all three resistors are connected in wye. The generator voltages (e. m. f.'s) are designated by the letter E, and the load voltages by the letter V, as is customary. The sum of the e. m. f.'s at terminal *O*

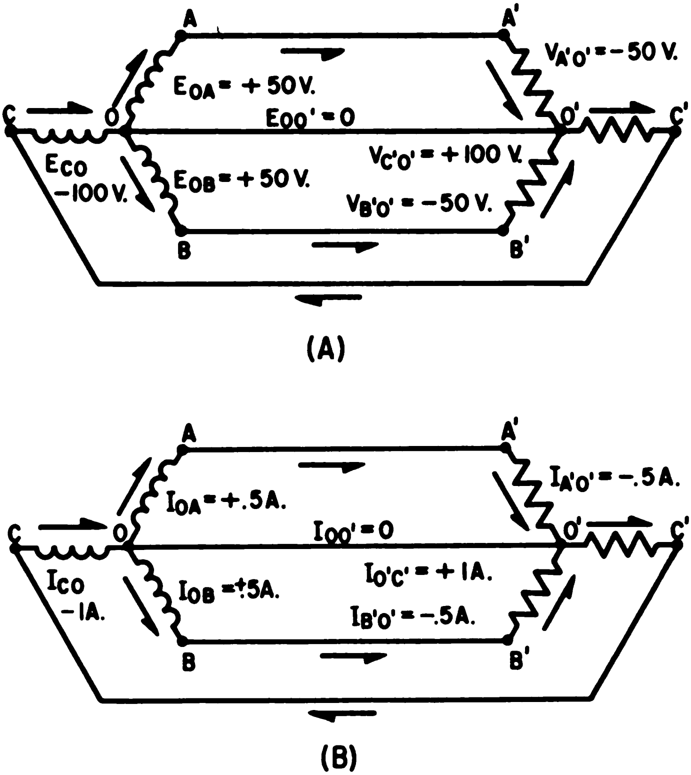


Figure 4-8.—Currents in a wye system.

can be seen as being equal to zero. Also, the sum of the load voltages at terminal *O'* is also zero. Thus it follows that there is no difference in potential between *O* and *O'*.

Figure 4-8 (B) shows that the sum of the currents entering and leaving terminals *O* and *O'* are also equal to zero. Since no potential difference exists between terminals *O* and *O'*, no current flows between them. This condition is true only when the system is balanced, and a system is balanced only when the following conditions exist:

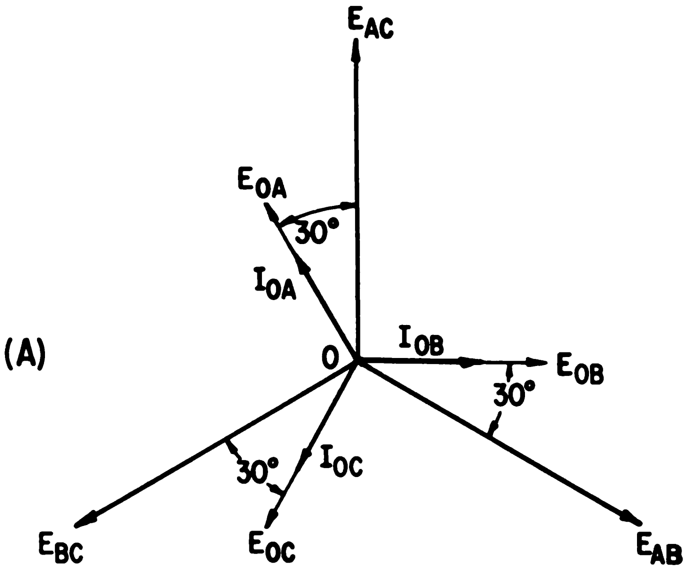
1. All phase e. m. f.'s are equal.
2. All phase load impedances are equal. (They may be reactive, but are considered balanced when each has the same reactive characteristic and power factor.)

3. All phase currents are equal.

The loads in figure 4-8 are not reactive, so the current and voltage of each resistor are in phase. Consequently, the coil currents and generated e. m. f.'s in the generator must also be in phase. Since it has already been established that the voltage of any wye line lags by 30° the voltage of the phase coil to which it is connected, then it follows that this line voltage also lags the coil current by 30°. This is true for a BALANCED system. That is, the 30° difference between line current (same as coil current) and line voltage in a wye-connected system is merely another wye system characteristic. It must not be confused with phase differences caused by reactive loads. Reactive loads may cause line current to be out of phase with coil voltage as well as being out of phase with line voltage.

Figure 4-9 (A) is the vector diagram of a generator supplying a nonreactive (resistive) load. Note that each phase current is in phase with its coil voltage, and that each line voltage is 30° out of phase with its coil voltage. This is as they should be. In part (B), assume the same generator is represented but that its load has been changed from a balanced resistive to a balanced inductive load. The inductive nature of the load phases will cause their currents to lag their voltages by the angle θ. This same lag is reflected automatically in the generator coils, since coil current, line current, and load current for a given phase are one and the same in a wye system. The lag for all three phases is the same, since it was assumed that the load is balanced. That is, each load phase has the same inductance. Part (B) thus shows how the coil current in the generator may be moved out of phase with coil voltage, by the type of load placed on the generator. (It is significant to note at this point that a capacitive load would have caused leading coil currents in figure 4-9.)

Regardless of load characteristics, any reference made to the power factor of a three-phase system refers to the phase angle between COIL voltage and COIL current. If line voltage rather than coil voltage were used as a reference, the factor $\theta - 30°$ or $\theta + 30°$ would have to be taken into consideration. Also, when an unbalanced condition exists, each phase may have a power factor



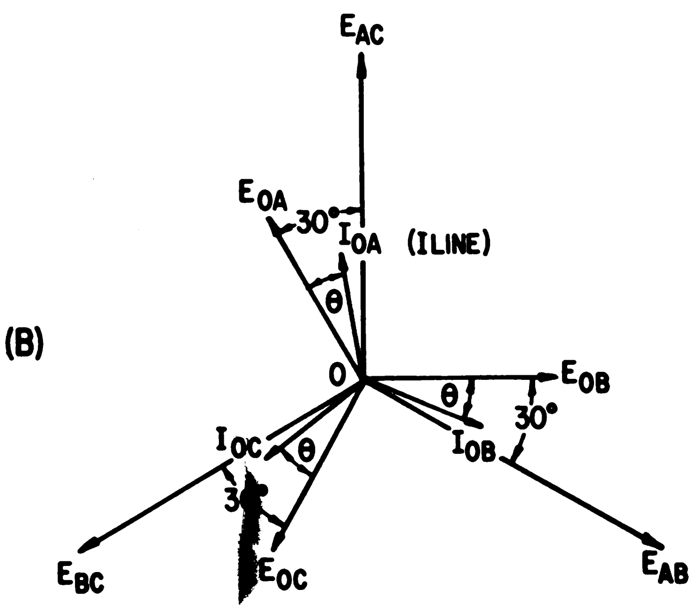


Figure 4-9.—(A) Balanced resistive load vectors; (B) balanced reactive load vectors.

angle different from the others, so that power must be computed for each phase separately to obtain total power. Under these circumstances, the term "system power factor" would be meaningless.

Power in Wye Systems

When an a-c generator or inverter is supplying a load, the total power being supplied is the sum of the power in all three phases. If the load is balanced, then the power being supplied by each generating coil is the same, and total power is $P_T = P_C \times 3$, where P_C is the power in any phase, or coil. The power for any coil is $P_C = E_C \times I_C$, where E_C is coil e. m. f. and I_C is coil current.

Line power (the same as total power) is determined by computations based on line voltage and current, rather than coil voltage and current. Total power expressed in terms of coil voltage and current is

$$P_T = 3 \times E_C \times I_C .$$

If power is to be expressed in terms of line voltage E_L and line current I_L, these quantities are substituted in the same formula, as follows:

$$E_L = \frac{E_C}{1.73}$$

also

$$I_L = I_C .$$

Substituting

$$P_T = 3 \times \frac{E_C}{1.73} \times I_C = 1.73 \times E_L \times I_L .$$

When a three-phase system is balanced, it can be seen that total power may be expressed in terms of line voltage and current, since all three respective values are equal, and it is assumed that individual phase powers are equal. However, in an unbalanced condition, individual phase powers are expressed separately, since each may have a power different from the others. Obviously, individual coil voltages and currents would have to be used. Total power in unbalanced systems would then be the sum of the individually determined phase powers.

When a balanced system is reactive, the power factor of the system must be used to indicate total TRUE POWER,

after total volt-amperes is determined. Assuming that the system is balanced, then the power factor angle θ is the same for all phases. This angle is considered to be the system power factor angle. Using line values for voltage and current in a reactive system, the formula $P_T = 1.73 \times E_L \times I_L$ will produce total volt-amperes. The total true power in watts is $P_{TP} = 1.73 \times E_L \times I_L \times \cos\theta$, which takes the system power factor into consideration.

When a system is both reactive and unbalanced, there is no such thing as a "system power factor," unless such a term is used to refer to the average of the individual phase angles. As stated before, total power in an unbalanced system is the sum of the power in all the phases. The solution of unbalanced systems will be discussed later in this chapter.

DELTA-CONNECTED SYSTEMS

Voltages in a Delta System

Figure 4-10 (A) shows a wye-connected generator with typical instantaneous values of coil e. m. f. Assume that the three voltmeters are capable of measuring instantaneous values of voltage. It can be seen that each voltmeter indicates the combined e. m. f. of two coils, because each pair of lines is connected across the ends of two coils.

In (B) of figure 4-10, the common coil ends are disconnected from each other, and these same coil ends are then reconnected by jumpers, as shown, to the outer ends of adjacent coils. Since any two points connected by a jumper are electrically the same, these two points may be joined directly, as shown in (C), and the jumper is eliminated. The generator is now connected in delta.

The instantaneous e. m. f.'s are the same in each generator coil in (C) as they were in (A). Only the coil interconnection has been changed in the generator. On the lines, however, significant changes in voltage have taken place, as shown by the voltmeters. These changes take place because each pair of lines is now connected across a SINGLE coil, rather than a pair of coils. This shows that, unlike wye-line voltages, the line-to-line voltage in a delta-connected system is always the same as the coil voltage; that is, $E_L = E_C$.

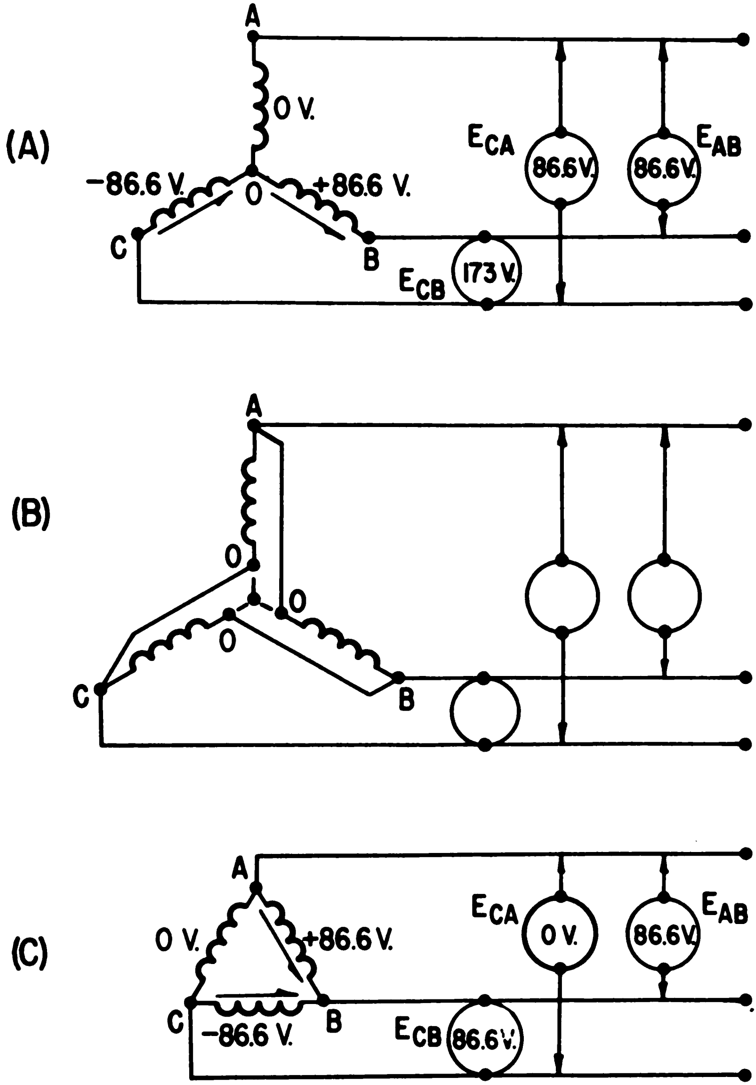


Figure 4-10.—Comparison of wye voltages to delta voltages.

It might seem at a glance that the line-to-line voltage across a particular delta coil would be affected by the e. m. f.'s in the remaining two coils, since the pair is

connected at each end to the same points across which voltage is being measured. This is not true, however, because the instantaneous magnitude and direction of e. m. f. in a particular coil is always equal and opposite to the SUM of the e. m. f.'s in the remaining two coils. Therefore, the measurable effect of the e. m. f.'s in the remaining two coils is zero. This may be seen more clearly when you consider the voltmeter reading E_{CA} in (C) of figure 4-10. The induced e. m. f. in coil *AC* is zero. Also, the sum of the e. m. f.'s E_{AB} and E_{CB} is zero. Therefore, any voltage measured across the coil *AC* is considered to be a voltage induced into that coil as a function of the generator. In a balanced delta system, no current will be impressed through a particular coil by the remaining two coils, but will flow as a result of its own induced voltage.

Because the e. m. f. in a particular coil is equal to the sum of the e. m. f.'s in the remaining two coils ($E_{CA} \oplus E_{BC} = 0$), then it follows that the sum of all three e. m. f.'s around the delta loop is zero at all times ($E_{CA} \oplus E_{BA} \oplus E_{BC} = 0$). This is shown in figure 4-11

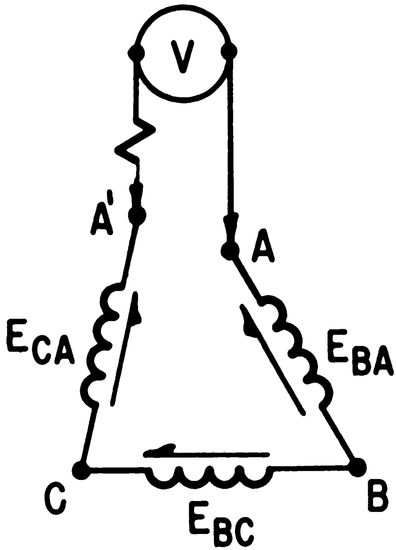


Figure 4-11.—Measurement of sum of delta loop voltages.

where the coil connections at point A are broken to form points A and A'. If a voltmeter were connected between these points as shown, it would indicate zero at all times, provided each coil is identical to the other. As a matter of fact, this is referred to as "closure voltage," and is one of the final items to be checked before the final connection is made when it is desired to operate a transformer or a-c generator in delta. That is, should a voltage exist from A to A' it would indicate that a coil is reversed. Correction would have to be made before making the final connections, or "closure" of the delta, to avoid short circuit current flow.

Currents in a Delta-Connected System

Figure 4-12 (A) represents a delta-connected generator with coil currents whose peak value is 10 amperes. Coils AC and CB are both at 60° from the zero X axis, so their instantaneous currents are of the magnitude shown ($10 \times \sin 60° = 8.66$ amp.). Since the two currents are acting in opposite directions around the delta loop, they are given opposite algebraic signs. In this explanation, coils lying above the Y axis will have positive voltages and currents, while those lying below the Y axis will have negative values.

The current carried by a delta line (I_L), such as the one connected to terminal C in figure 4-12 (A), is equal to the difference of the currents in the two coils to which the line is connected. Thus, in figure 4-12, the line current is $I_L = I_{CA} - I_{CB} = +8.66 - (-8.66)$ amps. Removing the parenthesis, changing the sign within, and combining terms, line current is $+8.66 + 8.66 = 17.32$ amperes. Note that the value for the leading phase current (I_{CB}) is the subtrahend. Figure 4-12 (B) is a vector representation of the instantaneous conditions shown in (A). The two coil current vectors, I_{AC} and I_{CB} are each 60° from the zero X axis, which corresponds to the coil positions shown in (A). Coil CB is leading, so its current vector is the subtrahend and must be reversed. When I_{CB} is reversed to I_{BC} and added to I_{CA}, the resultant is I_L. The length of vector I_L is 1.732 times the length of either coil current vector. This relation shows that the peak value of a delta line current is equal to 1.732 times the

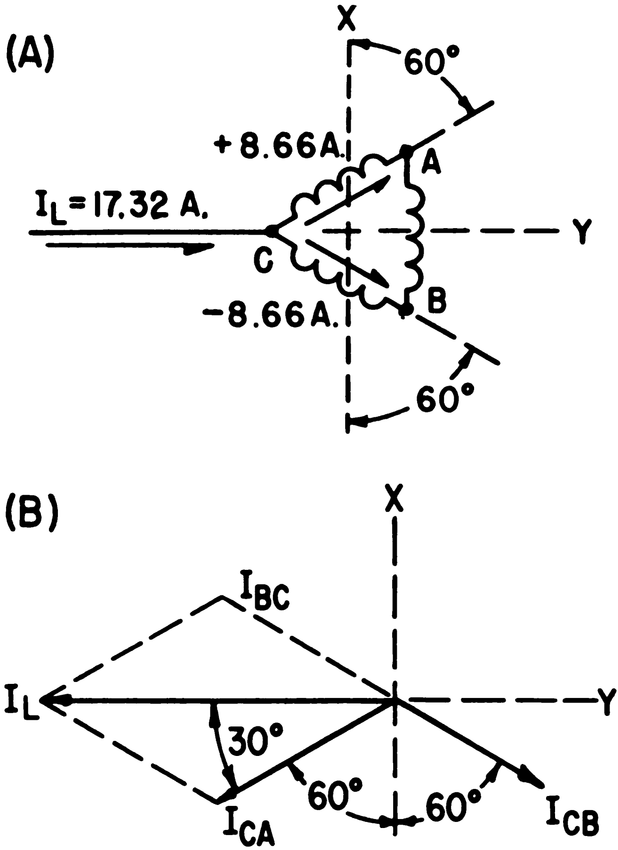


Figure 4-12.—Currents in the delta connection.

peak value of coil current. The same relation also applies to the effective value of line and coil current.

In figure 4-12 (B) it can also be seen that line current lags the nearest coil current by 30°. It must also lag line voltage by 30°, because line voltage, coil voltage, and coil current are in phase in a balanced delta system. This is shown more clearly in figure 4-13.

Figure 4-13 (A) shows that coil voltage and line voltage are one and the same and are labeled E_C (E_L) for all three delta phases. These coil voltages are in phase

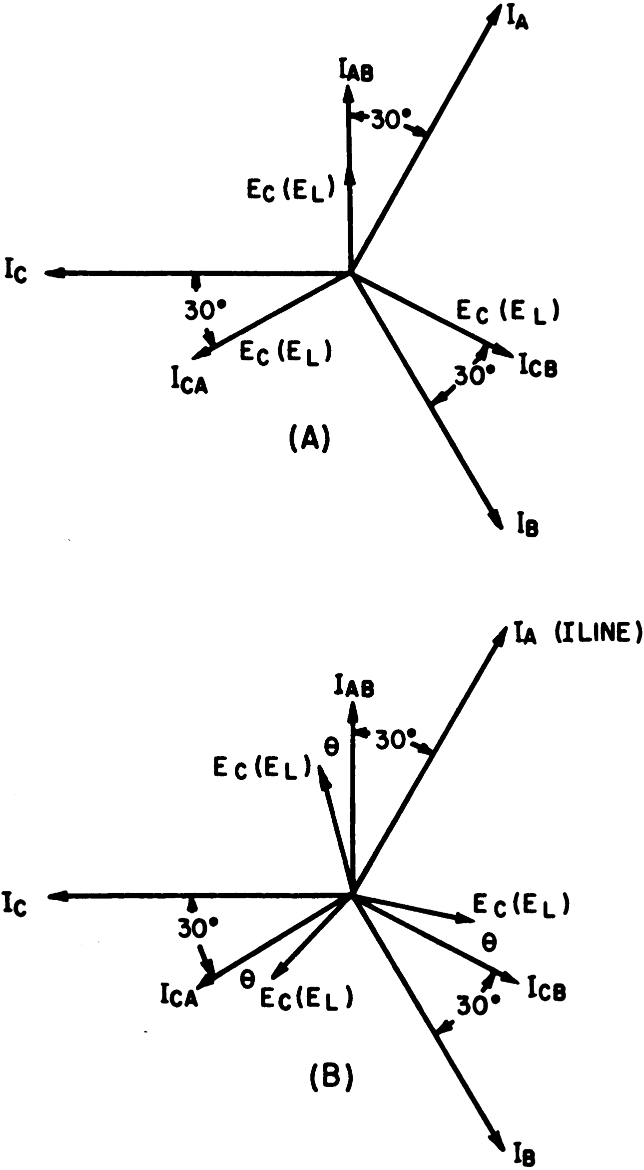


Figure 4-13.—(A) Vectors for balanced nonreactive delta; (B) vectors for balanced reactive delta.

with their coil currents I_{AB}, I_{CB}, and I_{CA}. As stated previously, line current lags coil current and voltage by 30° when the load is resistive and balanced. This relation for all three phases is shown in (A). That is, each of the line currents I_A, I_B, and I_C lag their respective nearest coil currents and voltages I_{AB}, I_{CB}, and I_{CA} by 30°.

Figure 4-13 (B) represents the same generator when a balanced inductive load is connected. Coil voltage and current are moved out of phase with each other by angle θ. When this happens, line current remains 30° out of phase with coil CURRENT, but is now $\theta + 30°$ out of phase with coil VOLTAGE.

At this point, you should refer to figure 4-9 (B). Remember that this vector diagram represents a WYE-CONNECTED generator supplying a balanced inductive load. Note that coil voltage E_{OA} and line voltage E_{AC} are considered fixed 30° apart, while coil current I_{OA} is varied by angle θ. However, in figure 4-13 (B) where the generator is connected delta, coil current I_{AB} and line current I_A are considered fixed 30° apart, while coil voltage E_C is varied by angle θ. In the wye system, line voltage and current are 30° minus θ° apart, while in the delta system they are 30° plus θ° apart, and the loads are identical in both cases. However, note that coil current lags coil voltage by θ in both systems. This is the reason for using coil phase angles for computing power instead of line phase angles, regardless of how the system is connected.

Power in Delta Systems

Power in a delta system is computed in practically the same manner as in a wye system. Coil, or phase power, is $P_C = E_C \times I_C$, and total power is three times the phase power, or $P_T = 3 \times P_C$. If line current and voltage are used, then $P_T = 1.732 \times E_L \times I_L$. When the load is not reactive, total power and true power are the same. With a reactive load, however, where coil voltage and coil current are not in phase, then $E_C \times I_C$ represents phase volt-amperes (apparent power) only. True power per phase would be $E_C \times I_C \times \cos\theta$, and VARS per phase would be $E_C \times I_C \times \sin\theta$. Total true power in the system would

be three times the phase true power, assuming each phase is the same, and total system VARS would be three times the phase VARS.

In an unbalanced system, total power is the sum of the power in all the phases, where each phase power is computed separately and then added to the others. As in the unbalanced wye system, the term "system power factor" is still practically meaningless when applied to an unbalanced delta system.

Figure 4-14 represents a single a-c generator and a balanced inductive three-phase load, connected first in wye, and then in delta. It can be seen that total apparent power, total true power, and total VARS are the same, respectively, in both systems when the following computations are applied to each.

The apparent power of one phase or coil is

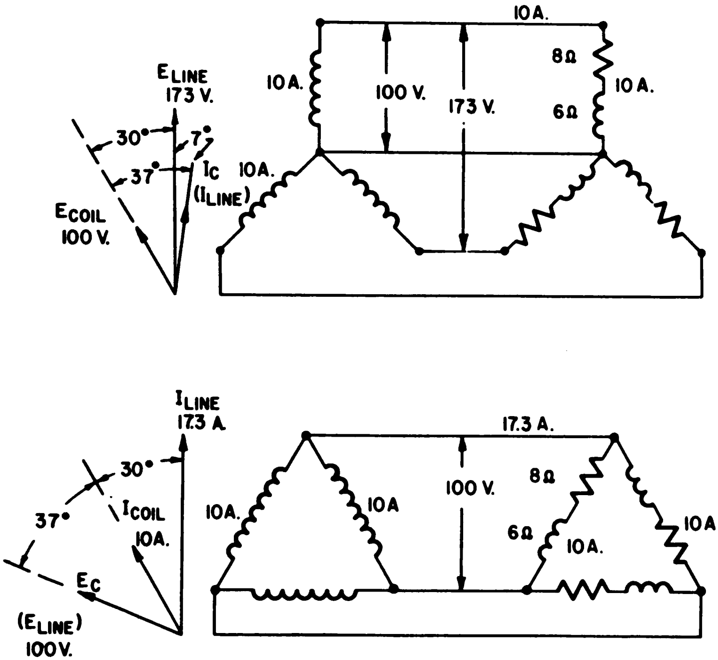


Figure 4-14.—Phase relation of line current to line voltage in wye and delta systems.

$$AP_C = E_C \times I_C$$

$$= 100 \times 10$$

$$= 1{,}000 \text{ VA.}$$

To determine true power and VARS, angle θ must be determined, and is done as follows. The impedance of a load phase is $8 + J6\ \Omega$. Therefore the tangent of angle θ is $J6/8$:

$$\text{Tan } \theta = \frac{J6}{8}$$

$$= 0.75$$

$$0.75 = \tan 37^\circ$$

$$\theta = 37^\circ.$$

True power per phase is $AP_C \times \cos \theta$.

$$P_{TP} = AP_C \times \cos 37^\circ$$

$$= 1{,}000 \times 0.8$$

$$= 800 \text{ watts.}$$

VARS per phase is $AP_C \times \sin \theta$.

$$VARS = AP_C \times \sin 37^\circ$$

$$= 1{,}000 \times 0.6$$

$$= 600 \text{ VA.}$$

Total true power is three times the true power per phase.

$$P_T = P_C \times 3$$

$$= 800 \times 3$$

$$= 2{,}400 \text{ watts.}$$

Total VARS is three times the VARS per phase.

$$VAR_T = VAR_C \times 3$$

$$= 600 \times 3$$

$$= 1{,}800 \text{ VA.}$$

Total apparent power is three times the phase apparent power.

$$AP_T = AP_C \times 3$$

$$= 1{,}000 \times 3$$

$$= 3{,}000 \text{ VA.}$$

Total line power is the same as total phase power.

From the foregoing, it can be seen that coil, or phase voltages, currents, and phase angles are the same for both the wye and delta systems. The major differences, then, lie in their respective values of line voltages, currents, and phase angles. Where one has a higher voltage on a given line (173 v. in the wye system, and 100 v. in the delta), the other will have a higher current on its corresponding line (17.3 amps. in delta system, and 10 amps. in the wye). However, one factor compensates for the other so that line power is equal in both systems. This is shown as follows:

Line power for either system is:

$$P = 1.73 \times E_L \times I_L \text{ VA.}$$

Substituting wye line values, line power is

$$P = 1.73 \times 173 \text{ volts} \times 10 \text{ amps.}$$

$$= 3{,}000 \text{ VA.}$$

Substituting delta lines values, line power is

$$P = 1.73 \times 100 \text{ volts} \times 17.3 \text{ amps.}$$

$$= 3{,}000 \text{ VA.}$$

Thus, in both systems, line power is 3,000 VA.

As already mentioned, another difference between the wye and delta system pertains to their respective line phase angles. This difference is shown in the vector diagrams in figure 4-14. To be correct, certain conditions must be met in both diagrams. Angle θ must be the same in either system with coil voltage leading coil current.

Also, wye line voltage must lag wye coil voltage by 30°, and delta line current must lag delta coil current by 30°. With θ equal to 37°, for the conditions shown, then the two vector diagrams are correct. It can be seen that under the load conditions shown, line current lags line voltage by 7° in the wye system, $(30° + \theta° = 30° + (-37°) = -7°)$. It can also be seen that line current leads line voltage by 67° in the delta system under identical load conditions $(30° - \theta = 30° - (37°) = 67°)$.

ADMITTANCE, CONDUCTANCE, AND SUSCEPTANCE

Symbology and General Formulae

A-c problems may be solved by methods other than those given in chapter 3. One of these methods involves the use of admittance in various mathematical processes.

The admittance of an a-c circuit is similar to the conductance of a d-c circuit, in that both are reciprocal quantities. Where conductance (symbol G) is the reciprocal of resistance ($1/R$), admittance (symbol Y) is the reciprocal of impedance ($1/Z$). Admittance is the complex reciprocal of complex impedance. That is, if the complex impedance of an a-c circuit is $2 - j4\,\Omega$, then the admittance (always written in complex form) is the reciprocal of that impedance, or $1/(2 - j4)$. The unit of admittance, as for conductance, is the *mho* symbolized by ℧. The two rectangular members comprising admittance are conductance (G) and susceptance (B). Susceptance is the reciprocal of reactance ($1/X_C$ or $1/X_L$). The general form for representing admittance is thus written $Y = G \pm jB$ mhos. To demonstrate, the admittance will be determined for a circuit whose impedance is $2 + j5\,\Omega$.

$$Y = \frac{1}{Z}$$

$$Y = \frac{1}{2 + J5}$$

$$= \frac{1}{2 + J5} \times \frac{2 - J5}{2 - J5}$$

$$= \frac{2 - J5}{29}$$

$$= 0.069 - J0.172 \ \mho .$$

Note that Y is composed of 0.069 mho of conductance and -J.172 mho of susceptance. Note also that the sign of the J operator for an impedance is reversed when that impedance is converted to its admittance. It is important that this relation be fixed firmly in mind. That is, where the J operator for an inductive impedance is plus, the J operator for its admittance is minus. It follows that the same inverse relation applies for capacitive impedance.

Admittance, rather than impedance, may often be used to an advantage in certain types of problems. It will be used in this chapter for the solution of unbalanced polyphase power systems, and in the application of Millman's theorem.

Solution of Circuits by Admittance

You have solved a-c problems using the parameters I, E, and Z. You can also solve these problems by the use of I, E, and Y. To do so, however, you must first become familiar with the way in which Y is used in relation to I and E.

Consider the following algebraic relation of Z to Y:

$$\frac{Y}{1} = \frac{1}{Z} \quad \text{or} \quad Y = \frac{1}{Z}$$

also

$$\frac{Z}{1} = \frac{1}{Y} \quad \text{or} \quad Z = \frac{1}{Y}.$$

Since Y is obviously the exact inverse of Z, then Y will always have the opposite effect in a mathematical formula that Z would have. That is, where Z is used as a multiplier, Y would be used as a divider, and vice versa. This inverted relation becomes apparent when you study the following columns in table 4-1. The left column consists of relations of I, E, and Z, with which you are familiar. The right-hand column gives the same relations, except that Z has been replaced by Y.

Table 4-1.—Relations of Y to Z.

$Z = \frac{1}{Y}$	$Y = \frac{1}{Z}$	(A)
$I = \frac{E}{Z}$	$I = E \times Y$	(B)
$E = I \times Z$	$E = \frac{I}{Y}$	(C)
$Z = \frac{E}{I}$	$Y = \frac{I}{E}$	(D)
$P = I^2 Z$	$P = \frac{I^2}{Y}$	(E)

In order to familiarize you with mathematical processes involving admittance, all of the five relations in the right-hand column of table 4-1 will be applied and their values solved for the circuit shown in figure 4-15, starting with (A). The total circuit admittance will be determined after solving the branch admittances Y_1 and Y_2 as follows:

$$Y_1 = \frac{1}{Z_1}$$

$$Y_1 = \frac{1}{6 - j8}$$

$$= \frac{1}{6 - j8} \times \frac{6 + j8}{6 + j8} \qquad \text{(A)}$$

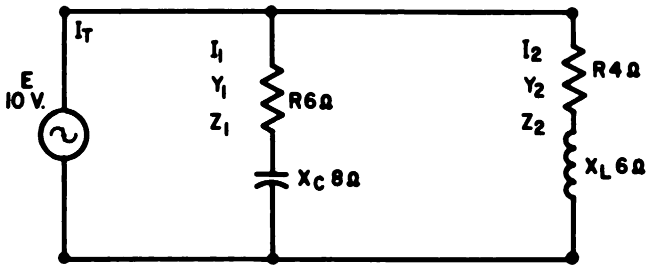


Figure 4-15.—Circuit for computing total admittance.

$$Y_1 = \frac{6+j8}{100}$$

$$= 0.06+j0.08 \text{ mho (Answer)}$$

$$Y_2 = \frac{1}{Z_2}$$

$$Y_2 = \frac{1}{4+j6}$$

$$= \frac{1}{4+j6} \times \frac{4-j6}{4-j6}$$

$$= \frac{4-j6}{52}$$

$$= 0.007-j0.115 \text{ mho (Answer).} \qquad \text{(A)}$$

To determine total circuit admittance, you need only to add all branch admittances. This is one of the advantages gained by the use of admittance. That is, the total admittance of a parallel circuit is determined as easily as the total resistance of a series circuit. This is true since both are determined by simply adding their respective values. Thus, total admittance (Y_T) in figure 4-15 is $Y_1 + Y_2$, added as follows: $(0.06+j0.08) + (0.077-j0.115)$, then $Y_T = 0.137-j0.035$.

Total current I_T is determined by multiplying voltage E by total admittance Y_T.

$$I_T = E \times Y_T$$

$$I_T = (10+j0) \times (0.137-j0.035) =$$

$$\begin{array}{l} 10.000+j0 \\ \underline{\;\;0.137-j0.035\;\;} \\ \;\;1.37+j0 \\ \underline{\qquad\qquad -j0.35-j^2 0} \\ \;\;1.37-j0.35 \text{ amp. (Answer).} \end{array} \tag{B}$$

Branch currents I_1 and I_2 could also be determined by multiplying the voltage by branch admittances Y_1 and Y_2.

If E is not known, but I_T and Y_T are given, E may be determined as follows:

$$E = \frac{I}{Y}$$

$$= \frac{1.37-j0.35}{0.137-j0.035}$$

$$= \frac{1.37-j0.35}{0.137-j0.035} \times \frac{0.137+j0.035}{0.137+j0.035}$$

$$= \frac{0.20+j0}{0.020}$$

$$= 10+j0 \text{ volts (Answer).} \tag{C}$$

Where I_T and E are known, and Y_T must be determined, then:

$$Y_T = \frac{I_T}{E}$$

$$= \frac{1.37-j0.35}{10+j0}$$

$$= \frac{1.37-j0.35}{10+j0} \times \frac{10-j0}{10-j0}$$

$$= \frac{13.7-j3.5}{100}$$

$$= 0.137-j0.035 \text{ mho (Answer).} \tag{D}$$

Power can be determined when current I_T and admittance Y_T are known.

$$P = \frac{I^2{}_T}{Y_T}$$

$$= \frac{(1.37 - j0.35)^2}{0.137 - j0.035}$$

$$= \frac{1.76 - j0.96}{0.136 - j0.035}$$

$$= \frac{1.76 - j0.96}{0.137 - j0.035} \times \frac{0.137 + j0.035}{0.137 + j0.035}$$

$$= \frac{0.274 - j0.0694}{0.0310}$$

$$= 8.84 + j3.95 \text{ VA. (Answer)} \qquad \text{(E)}$$

MILLMAN'S THEOREM

This theorem pertains to a special method of analysis for two-node networks. A two-node network is one consisting of two or more branches connected in parallel. The "nodes" of such a network are those two points where all branch ends terminate. For instance, the standard aircraft d-c power system is a typical two-node network. One node is the d-c power bus, where all d-c branches, including generators and batteries, terminate at a common high-potential point. The other node is the airframe, where all branches terminate to ground, or a common low-potential point.

Millman's theorem enables you to determine the node-to-node voltage of a parallel network when more than one source of potential, each different from the other, is supplying power. Such a condition exists, for instance, when a 28-volt generator and a 24-volt battery are connected to the same bus. Depending on the size of the load connected, bus voltage (node-to-node voltage) will probably be between 28 and 24 volts. However, if the load were heavy enough, bus voltage could be less than 24 volts. The problem of computing the current supplied

by each power source under various load conditions would be simplified if the bus voltage could be determined for each condition. This is exactly what can be done by use of the Millman method where the bus and ground are treated as the two nodes of a parallel network.

Figure 4-16 shows two unequal current sources connected in parallel between the common nodes O and N. E_1 represents a generator whose e. m. f. is 28 volts, and whose internal resistance is R_1. The conductance of R_1 is G_1, and e_1 represents the generator's internal voltage drop when it is supplying current. E_2 is a battery whose e. m. f. is 24 volts, and whose internal resistance is R_2. The conductance of R_2 is G_2, and e_2 represents the battery's internal voltage drop when it is either supplying current or is being charged. The system load is R_3. The problem is to determine the current supplied by the generator (I_1) and battery (I_2) when the load is as shown. This can be done when the node-to-node voltage E_{ON} is known. (E_{ON} is merely the terminal voltage of the current sources under load.) Millman's theorem states that the voltage across a two-node network is equal to the sum of the currents in all the potential sources, divided by the sum of all branch conductances. The source currents are expressed in terms of source e. m. f. and the conductance of the source's internal resistance, ($I = E \times G$). The general mathematical form of Millman's theorem is

$$E_{ON} = \frac{\text{ALL SOURCE CURRENTS}}{\text{ALL BRANCH CONDUCTANCES}}$$

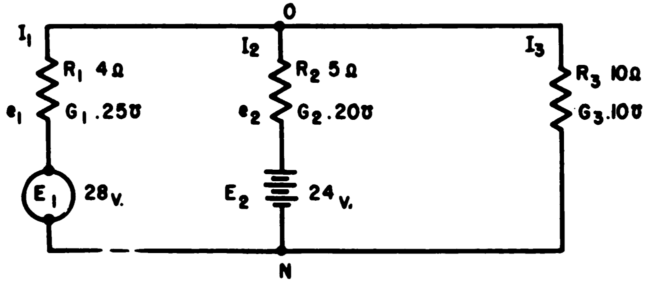


Figure 4-16.—A two-node network with unequal current sources.

When this formula is applied to figure 4-16, it is as follows:

$$E_{ON} = \frac{I_1 + I_2}{G_1 + G_2 + G_3}$$

$$E_{ON} = \frac{E_1G_1 + E_2G_2}{G_1 + G_2 + G_3}$$

$$= \frac{(28 \times 0.25) + (24 \times 0.20)}{0.25 + 0.20 + 0.10}$$

$$= \frac{7 + 4.8}{0.55}$$

$$= 21.45 \text{ volts.}$$

With E_{ON} known, the load current I_3 can be readily determined.

$$I = E \times G$$

$$I_3 = E_{ON} \times G_3$$

$$= 21.45 \times 0.1$$

$$= 2.145 \text{ amps.}$$

The internal voltage drop of the generator (e_1) must be the difference between its generated e. m. f. and its terminal voltage.

$$e_1 = E_1 - E_{ON}$$

$$= 28 - 21.45$$

$$= 6.55 \text{ volts.}$$

The internal voltage drop of the battery is

$$e_2 = E_2 - E_{ON}$$

$$= 24 - 21.45$$

$$= 2.55 \text{ volts.}$$

Generator current can now be determined.

$$I = E \times G$$

$$I_1 = e_1 \times G_1$$

$$= 6.55 \times 0.25$$

$$= 1.635 \text{ amps.}$$

Battery current can also be determined.

$$I_2 = e_2 \times G_2$$

$$= 2.55 \times 0.20$$

$$= 0.510 \text{ amp.}$$

As a final check, I_3 should equal the sum of I_2 and I_1.

$$I_1 + I_2 = I_3$$

$$1.635 + 0.510 = 2.145$$

$$2.145 = 2.145 \text{ (check).}$$

It can readily be seen that the use of the Millman formula is a more convenient method for solving this type of problem than the application of Kirchoff's laws, or the various mesh methods. The Millman method does not require the use of lengthy simultaneous linear equations. In addition to its usefulness as a method of solving d-c systems, it is also extremely useful in the analysis and solution of polyphase a-c systems. The major difference in the two applications is that when the Millman theorem is applied to a-c systems, admittances, rather than simple conductances, are used in the formula.

As previously stated, the Millman method enables you to resolve a number of unequal potentials into a single node-to-node value. This is the key to its usefulness in solving polyphase a-c problems. The coil e. m. f.'s in a three-phase system are always different from each other if their instantaneous values are considered. Therefore,

they may be considered as three instantaneously unequal current sources, and their net result may be resolved into a single instantaneous value when the three e. m. f.'s are connected between two nodes. However, even instantaneous values will establish phase relations which are constant.

Figure 4-17 represents a balanced wye-connected system with no neutral conductor. Part (B) shows how each instantaneous coil e. m. f. is identified by its rectangular coordinates. The instantaneous magnitude and direction of each coil e. m. f. is also indicated by the arrows in part (A). The three coils are supplying power between the two nodes O and O', so their instantaneous resultant potential $E_{OO'}$ may be determined by the use of Millman's theorem. The three loads are equal, so their admittances are equal. Since the system is balanced, there should be no difference in potential between O and O'.

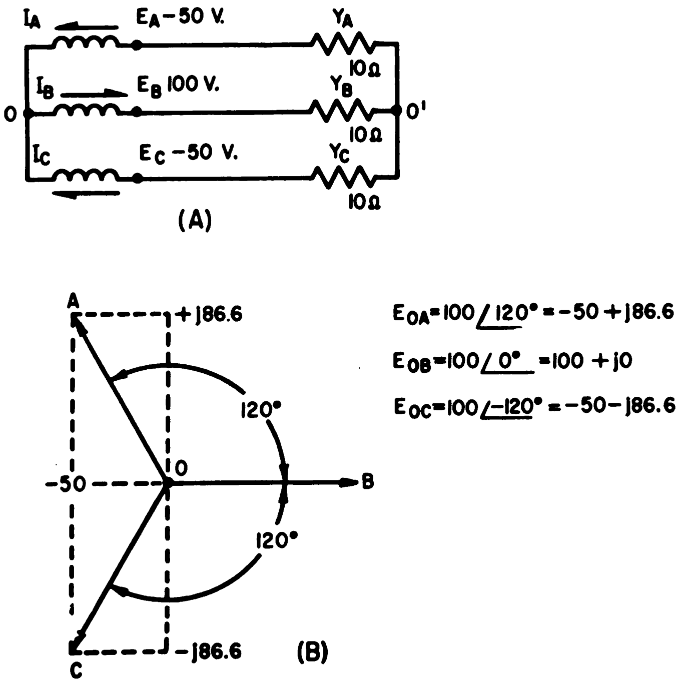


Figure 4-17.—Instantaneous representation of three-phase voltages.

That is, $E_{OO'} = 0$. This will be proven by the application of Millman's theorem. The load admittances must be solved first, since they appear in the theorem formula.

$$Y_A = \frac{1}{Z_A}$$

$$= \frac{1}{10 + j0}$$

$$= \frac{1}{10 + j0} \times \frac{10 - j0}{10 - j0}$$

$$= \frac{10 - j0}{100}$$

$$= 0.1 - j0.$$

All the load admittances are equal, so $0.1 - j0$ ℧ is the admittance for any of the three branches. Solving for $E_{OO'}$ can now be carried out.

$$E_{OO'} = \frac{I_A + I_B + I_C}{Y_A + Y_B + Y_C}$$

$$= \frac{E_A Y_A + E_B Y_B + E_C Y_C}{Y_A + Y_B + Y_C} =$$

$$\frac{(-50+j86.6)(0.1+j0) + (100+j0)(0.1+j0)+(-50-j86.6)(0.1+j0)}{(0.1+j0) + (0.1+j0) + (0.1+j0)}$$

$$= \frac{(-5+j8.66) + (10+j0) + (-5-j8.66)}{0.3+j0}$$

$$= \frac{0}{0.3+j0}$$

$$E_{OO'} = 0 .$$

This proves what was already stated—that $E_{OO'}$ is zero for a balanced system. However, you should study carefully the manner in which the system quantities were

operated with one another. In this way you will be able to solve unbalanced systems more readily.

UNBALANCED POLYPHASE SYSTEMS

Up to this point, only balanced polyphase systems have been discussed. For purposes of explanation, it was assumed that ideal conditions existed, where all phase voltages, currents, and power rates were equal. Moreover, it was assumed that the three-phase voltages were exactly 120° apart in their time-phase relations to each other. In practice, however, such ideal conditions rarely exist.

It is practically impossible to connect a number of separate loads to a three-phase generator in such a way that the demand on each phase is exactly equal to the demand on any other phase. This is especially true when the types of loads are not identical (motors, lighting, transformers, etc.). In addition to unequal wattage demands, each load component will most likely have a different reactive characteristic. The resulting unequal phase currents will produce an unbalanced condition in the system's line voltages. They will either be unequal in magnitude or no longer 120° apart. In many cases both conditions will exist. The amount of unbalance or phase displacement depends on the differences of the loads and the loading characteristics of the generator. Obviously, this unbalance must be kept at a minimum, and should be of prime consideration when loads are either removed from or connected in a polyphase power system. You should be familiar with the causes and effects and the methods of correcting for unbalanced systems.

CAUSES OF UNBALANCE.—In three-phase systems the causes of unbalance are: (1) Single-phase loads of unequal volt-ampere demand; (2) loads of equal volt-ampere demand, but with unequal reactive characteristics (power factor); and (3) fault conditions.

EFFECTS OF UNBALANCED LOADING.—The effects of unbalanced loading depend on the characteristics of the generator, the impedance of the line conductors, and the design of the generator's voltage regulator circuit. Some regulators sense the voltage of one phase, while others sense the average of all three phases. In general, excessive current in one phase will cause a rise in voltage

in at least one of the other phases. At the same time, the phase voltages will no longer be at the desired 120° from each other.

Another effect of unbalanced loading is that the total capacity of the generator is reduced. For example, consider a 6,000 VA. generator with a rating of 2,000 VA. for each phase. Assume that a single-phase load of 500 VA. has been placed on one phase. The maximum additional three-phase load the generator can now carry is 4,500 VA., with 1,500 VA. being placed on each phase. At this time, the preloaded phase is carrying 2,000 VA., its rated capacity, while two phases are carrying only 1,500 VA. each. No additional three-phase load may be added without danger of overloading the phase carrying 2,000 VA. Thus, by connecting an unbalanced load, the total capacity of the generator has been reduced from 6,000 VA. to 5,000 VA. (2,000 + 1,500 + 1,500 = 5,000).

The performance specifications a power source (aircraft a-c generator and voltage regulator) must meet to be acceptable to the Navy are given in Military Specification MIL-G-6099. The following is taken from that specification.

UNBALANCED LOADS.—The effects of single-phase and unbalanced three-phase loads on the voltage balance of a three-phase generator shall be determined as follows, at both maximum and minimum rated speeds:

1. Starting with the generator carrying no load, a nonreactive (unity power factor) load shall be placed on one phase. This load shall require first 1/3 and then 2/3 of the rated output current from that phase.

2. Starting with the generator carrying a three-phase unity power factor load demanding 1/3 of the rated output from each phase, an additional unity power factor load will be placed on one phase. The additional load will demand first 1/3 and then 2/3 of the rated output of that phase, so that finally the one phase is supplying full rated output current.

3. Starting with the generator carrying a three-phase unity power factor load demanding 2/3 of the rated output from each phase, an additional unity power factor load will be placed on one phase. The additional load will demand 1/3 of the rated output of that phase, so that the one phase is supplying full rated output current.

Under the conditions just described, the maximum voltage unbalance shall not exceed 4 percent. The percentage of unbalance is computed as follows:

$$\% \text{ unbalance} = \frac{100 \times \text{maximum deviation from average voltage}}{\text{average voltage}}.$$

The average voltage is the arithmetical sum of the three unequal voltages divided by three. Maximum deviation is the difference between the voltage of the phase that is farthest from average, and the average.

In addition to the limitation of 4 percent placed on the voltage magnitude unbalance, a limitation is also placed on the time phase displacement between phases. The phase displacement must be 120°, ±5°. That is, no two phases may be nearer than 115° to each other, nor more than 125° apart.

SOLUTION OF UNBALANCED SYSTEMS

Solution of Unbalanced Delta Systems

The solution of an unbalanced delta system is greatly facilitated by the fact that there are three separate current loops. Each loop may be treated as a simple single-phase circuit. In figure 4-18 (A), the three loops are BAA'B'B, CBB'C'C and ACC'A'A. In each loop there is one phase coil e. m. f. and one phase load impedance. Consequently, each instantaneous loop current can be determined by use of its instantaneous e. m. f. and load impedance. This will yield instantaneous phase, or coil, current only. The line currents I_A, I_B and I_C will be different from the phase currents because each line is part of two loops. Consequently, any line current is a combination of two loop currents.

In a balanced condition, it was shown that either peak or average delta line current was equal to either peak or average phase current times $\sqrt{3}$, or 1.73. It was also shown that the three line currents were 120° apart. In an unbalanced condition, however, these relations are generally no longer true. However, even when the delta system is unbalanced, it can still be stated that any line

current is equal to the difference of the two phase currents to which the line is connected. For this reason the phase currents must be determined prior to determining the line currents. This will be done for the system in figure 4-18 (A).

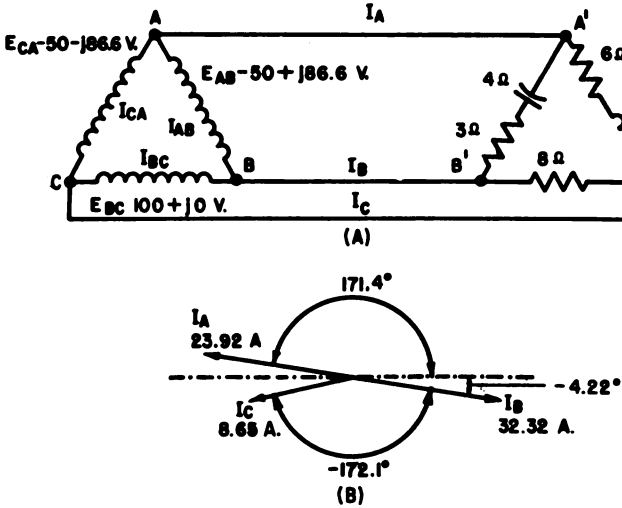


Figure 4-18.—(A) Unbalanced delta system; (B) unbalanced current vectors.

$$E_{AB} = -50 + J86.6 \text{ V.}$$

$$Z_{A'B'} = 3 - J4 \ \Omega$$

$$I_{AB} = \frac{E_{AB}}{Z_{A'B'}}$$

$$= \frac{-50 + J86.6}{3 - J4}$$

$$= \frac{-50 + J86.6}{3 - J4} \times \frac{3 + J4}{3 + J4}$$

$$= \frac{-496.4 + J59.8}{25}$$

$$= -19.8 + J2.39 \text{ amp.}$$

$$E_{BC} = 100 + j0 \text{ V.}$$

$$Z_{B'C'} = 8 + j0 \ \Omega$$

$$I_{BC} = \frac{E_{BC}}{Z_{B'C'}}$$

$$= \frac{100 + j0}{8 + j0}$$

$$= \frac{100 + j0}{8 + j0} \times \frac{8 - j0}{8 - j0}$$

$$= \frac{800 + j0}{64}$$

$$= 12.5 + j0 \text{ amp.}$$

$$E_{CA} = -50 - j86.6 \text{ V.}$$

$$Z_{C'A'} = 6 + j8 \ \Omega$$

$$I_{CA} = \frac{E_{CA}}{Z_{C'A'}}$$

$$= \frac{-50 - j86.6}{6 + j8}$$

$$= \frac{-50 - j86.6}{6 + j8} \times \frac{6 - j8}{6 - j8}$$

$$= \frac{392 - j119}{100}$$

$$= 3.92 - j1.19 \text{ amp.}$$

With the phase currents known, the line currents can now be determined.

$$I_A = I_{AB} - I_{CA}$$

$$= (-19.8 + j2.39) - (3.92 - j1.19)$$

$$= -19.8 + j2.39 - 3.92 + j1.19$$

$$= -23.72 + j3.58 \text{ amp.}$$

$$I_B = I_{BC} - I_{AB}$$

$$= (12.5 + j0) - (-19.8 + j2.39)$$

$$= 12.5 + j0 + 19.8 - j2.39$$

$$= 32.3 - j2.39 \text{ amp.}$$

$$I_C = I_{CA} - I_{BC}$$

$$= (3.92 - j1.19) - (12.5 + j0)$$

$$= 3.92 - j1.19 - 12.5 - j0$$

$$= -8.58 - j1.19 \text{ amp.}$$

If the solutions for line currents are correct, the sum of the line currents will be zero.

$$I_A + I_B + I_C = 0$$

$$\begin{array}{r} -23.72 + j3.58 \\ 32.30 - j2.39 \\ -8.58 - j1.19 \\ \hline 0 + j0 \end{array} \quad \text{(Check).}$$

Further clarification of unbalanced delta current relations will be obtained by converting the line currents from rectangular to polar form and constructing a vector diagram. The polar form of the line currents are as follows:

$$I_A = -23.72 + j3.58 = 23.92 \underline{/171.4^\circ}$$

$$I_B = 32.3 - j2.39 = 32.32 \underline{/-4.22^\circ}$$

$$I_C = -8.58 - j1.19 = 8.65 \underline{/-172.1^\circ}.$$

When these three current vectors are used to construct a diagram, the result is as shown in figure 4-18 (B). In

this case, the vectors represent instantaneous current magnitudes by their length. Since these vectors would have been 120° apart had the system been balanced, it can be seen that the degree of unbalance in figure 4-18 (B) is quite severe in both magnitude and phase displacement. The phase displacement between I_A and I_B is $171.4° + 4.22° = 175.62°$. Between I_B and I_C the displacement is $172.1° - 4.22° = 167.88°$. Between I_C and I_A it is $(180° - 171.4°) + (180° - 172.1°) = 8.6° + 7.9° = 16.5°$.

The power in each phase is the phase voltage times the phase current. Remember that the conjugate of the voltage must be used.

$$\begin{aligned}
P_{AB} &= E_{AB} \times I_{AB} \text{ VA.} \\
&= (-50 + j86.6) \times (-19.8 + j2.39) \\
&= (-50 - j86.6) \times (-19.8 + j2.39) \\
&= 990 + j1{,}593 - j^2\,207 \\
&= 1{,}197 + j1{,}593 \text{ VA.}
\end{aligned}$$

$$\begin{aligned}
P_{BC} &= E_{BC} \times I_{BC} \\
&= (100 + j0) \times (12.5 + j0) \\
&= (100 - j0) \times (12.5 + j0) \\
&= 1{,}250 + j0 + j^2 0 \\
&= 1{,}250 + j0 \text{ watts}
\end{aligned}$$

$$\begin{aligned}
P_{CA} &= E_{CA} \times I_{CA} \\
&= (-50 - j86.6) \times (3.92 - j1.19) \\
&= (-50 + j86.6) \times (3.92 - j1.19) \\
&= -196 + j398.5 - j^2 103 \\
&= -93 + j398.5 \text{ VA.}
\end{aligned}$$

With each phase power known, total power can be determined. Total power in an unbalanced system is the sum of the phase powers. The total instantaneous power for the system in figure 4-18 is

$$P_T = P_{AB} + P_{BC} + P_{CA}$$

$$= (1{,}197 + j1{,}593) + (1{,}250 + j0) + (-93 + j408.5)$$

$$= 2{,}354 + j2{,}001.5 \text{ VA.}$$

Solution of Unbalanced Wye Systems

In general, it is important that the AE be more familiar with the analysis and solution of unbalanced wye systems than unbalanced delta systems. This is true because military specifications require that the a-c power systems in naval aircraft be connected in wye. For this reason the solution of wye systems will be given somewhat more complete coverage than the solution of delta systems. This coverage will be given in the form of a series of examplary problems.

Problem 1. For the unbalanced three-wire system shown in figure 4-19 (A), solve for the line currents and the voltage across each load phase, with the instantaneous generated e. m. f.'s as shown.

NOTE: In a four-wire system, the neutral of the load is connected to the neutral of the source, so that the voltage and current of each phase loop may be treated and solved separately. In a three-wire system, the neutrals are not connected, and are allowed to shift away from each other in what is called a "floating neutral." Under these conditions, it is necessary to determine the actual voltage between the neutrals before attempting to solve for the phase currents. This must be done, because the neutral-to-neutral voltage may aid one phase e. m. f. while bucking another. Since the neutrals may be treated as the two nodes mentioned in Millman's theorem, this theorem may be used to solve the problem. The voltage between the nodes O and N in figure 4-19 (A) is

$$E_{ON} = \frac{E_A Y_1 + E_B Y_2 + E_C Y_3}{Y_1 + Y_2 + Y_3}.$$

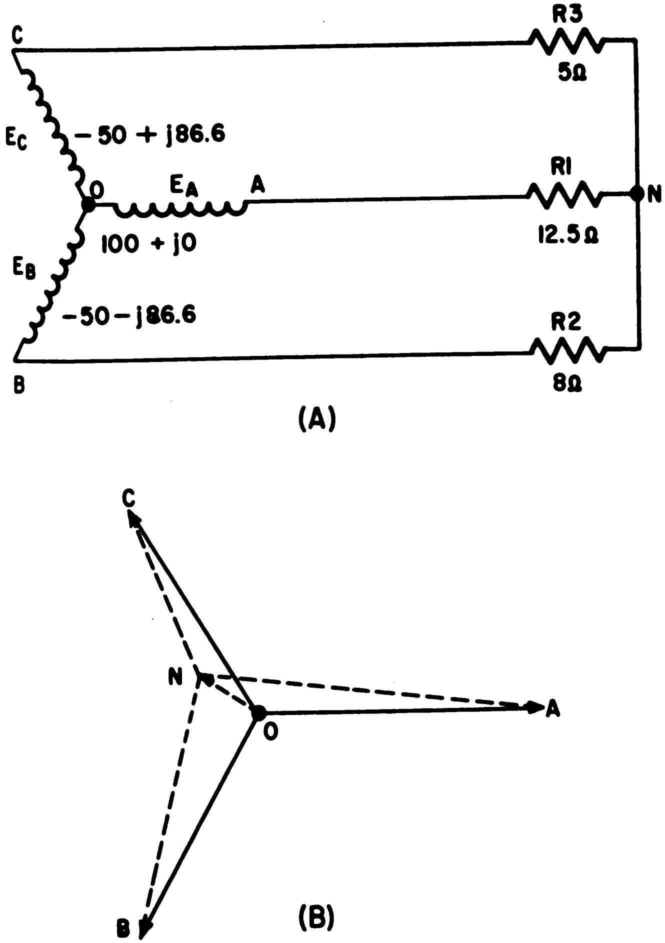


Figure 4-19.—(A) Unbalanced 3-wire wye; (B) difference of generated e. m. f.'s and load voltages.

Impedances:	Admittances:
$R_1 = 12.5 + j0\ \Omega$	$Y_1 = 0.08\ ℧$
$R_2 = 8.0 + j0\ \Omega$	$Y_2 = 0.125\ ℧$
$R_3 = 5.0 + j0\ \Omega$	$Y_3 = 0.200\ ℧$
Summation of	$Y's = 0.405\ ℧.$

Due to the unbalanced load, it can be seen that the voltage across each load phase is not equal to the fundamental generated e. m. f. of the generator phase to which it is connected. Figure 4-19 (B) represents the phase load voltage vectors E_{NA}, E_{NB}, and E_{NC} superimposed on the fundamental generated voltages E_{OA}, E_{OB}, and E_{OC}. The magnitude and direction of E_{ON} can thus be depicted as a line drawn from the generator neutral O to the load neutral N. It can be seen how E_{ON} acts to increase E_{OA} to produce E_{NA}, to increase E_{OB} to E_{NB}, and to decrease E_{OC} to E_{NC}.

Problem 2. Figure 4-20 represents a four-wire unbalanced wye system, with a voltage regulator designed to maintain phase A terminal voltage at 120 volts. In addition, the generator windings have an inductive reactance of 3 Ω in each winding. The system is simplified for solution as shown in figure 4-20 (B).

Phase A is used as a reference because the voltage regulator will always maintain its terminal voltage at 120 volts.

$$I_A = \frac{V_{OA}}{Z_A} = \frac{120+j0}{5} = 24+j0$$

$$IX_S \text{ of generator} = (24+j0) \times j3 = 0+j72$$

$$E_{OA} = V_{OA} + IX_S = (120+j0) + (0+j72) = 120+j72$$

$$E_{OA} = 140 \underline{/31^\circ}.$$

E_{OB} and E_{OC} may be determined by knowing that the excitation field is common to all three phases and that the phase windings are displaced by 120 electrical degrees.

$$E_{OB} = 140 \underline{/31^\circ} \times 1 \underline{/-120^\circ} = 140 \underline{/-89^\circ}$$

$$E_{OC} = 140 \underline{/31^\circ} \times 1 \underline{/120^\circ} = 140 \underline{/151^\circ}$$

$$E_A Y_1 = (100+j0) \times 0.08 = 8.0+j0$$

$$E_B Y_2 = (-50-j86.6) \times 0.125 = -6.25-j10.83$$

$$E_C Y_3 = (-50+j86.6) \times 0.20 = -10.0+j17.32$$

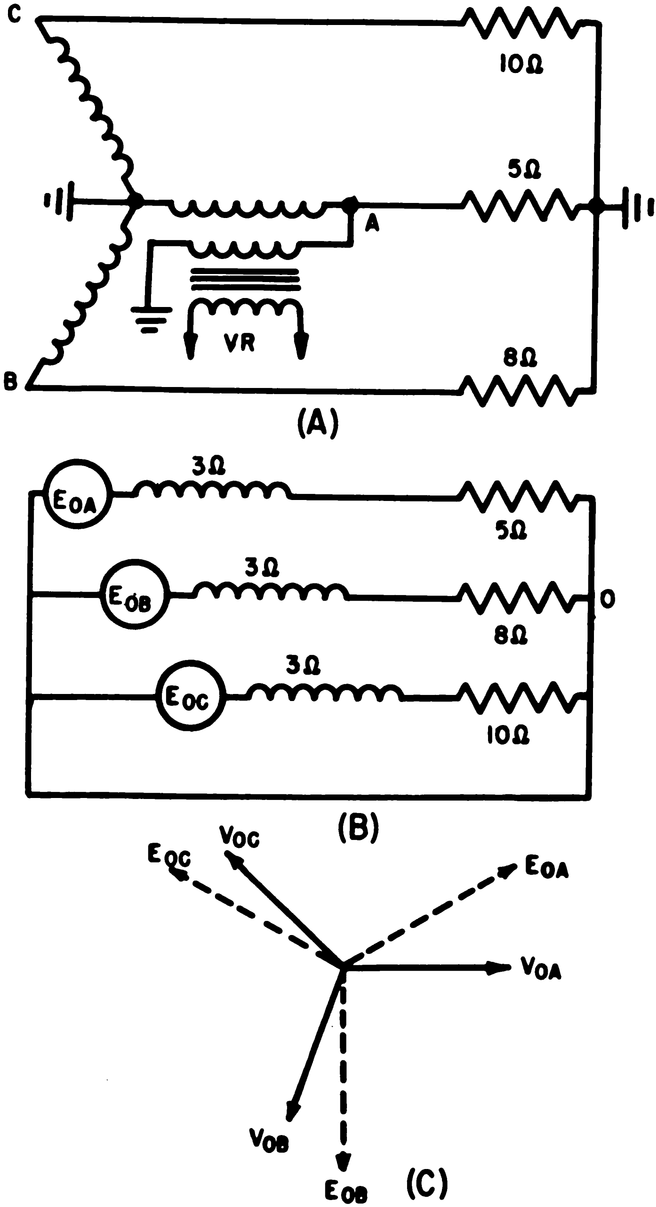


Figure 4-20.—(A) Four-wire unbalanced wye; (B) simplified system; (C) difference of fundamental and terminal voltages.

Summation of EY's $= -8.25 + J6.51$

$$E_{ON} = \frac{E_A Y_1 + E_B Y_2 + E_C Y_3}{Y_1 + Y_2 + Y_3} = \frac{-8.25 + J6.51}{0.405}$$

$$= -20.37 + J16.07.$$

Solution for line currents:

$$I_A = (E_A - E_{ON})\ Y_1$$

$$= [(100 + J0) - (-20.37 + J16.07)] \times 0.08$$

$$= (100 + 20.37 - J16.07) \times 0.08$$

$$= (120.37 - J16.07) \times 0.08$$

$$= 9.63 - J1.28 = 9.72\ \underline{/-7.6^\circ} \text{ amps.}$$

$$I_B = (E_B - E_{ON})\ Y_2$$

$$= [(-50 - J86.6) - (-20.37 + J16.07)] \times 0.125$$

$$= (-50 - J86.6 + 20.37 - J16.07) \times 0.125$$

$$= (-29.63 - J102.65) \times 0.125$$

$$= -3.70 - J12.83 = 13.3\ \underline{/-163.9^\circ} \text{ amps.}$$

$$I_C = (E_C - E_{ON})\ Y_3$$

$$= [(-50 + J86.6) - (-20.37 + J16.07)] \times 0.2$$

$$= (-50 + J86.6 + 20.37 - J16.07) \times 0.2$$

$$= (-29.63 + J70.53) \times 0.2$$

$$= -5.93 + J14.11 = 15.3\ \underline{/157.2^\circ} \text{ amps.}$$

NOTE: As there is no neutral conductor for current, the sum of the line currents must equal zero.

$$I_A = 9.63 - j1.28$$

$$I_B = -3.70 - j12.83$$

$$I_C = -5.93 + j14.11.$$

Summation of I's $= 0.0 + j0.0$.

The phase voltages of the load are:

$$E_{NA} = I_A \times R_1 = 9.72 \times 12.5 = 121.5 \text{ volts}$$

$$E_{NB} = I_B \times R_2 = 13.3 \times 8 = 106.0 \text{ volts}$$

$$E_{NC} = I_C \times R_3 = 15.3 \times 5 = 76.5 \text{ volts.}$$

It is now possible to solve for current and terminal voltages of phase B and C.

$$I_B = \frac{E_{OB}}{Z_B} = \frac{140 \angle -89^\circ}{8 + j3} = \frac{140 \angle -89^\circ}{8.54 \angle 20.6^\circ} = 16.4 \angle -109.6^\circ$$

$$= -5.5 - j15.4$$

$$V_{OB} = 8 \times 16.4 \angle -109.6^\circ = 131 \angle -109.6^\circ$$

$$I_C = \frac{E_{OC}}{Z_C} = \frac{140 \angle 151^\circ}{10 + j3} = \frac{140 \angle 151^\circ}{10.4 \angle 16.7^\circ} = 13.4 \angle 134.3^\circ$$

$$= -9.35 + j9.6$$

$$V_{OC} = 10 \times 13.4 \angle 134.3^\circ = 134 \angle 134.3^\circ.$$

The current carried by the neutral (ground) wire will be equal to the vector sum of the separate line currents.

$$I_A = 24.0 + j0.0$$

$$I_B = -5.5 - j15.4$$

$$I_C = -9.35 + j9.6$$

$$I_N = 9.15 - j5.8 = 10.8 \angle -32.4^\circ.$$

This current is a result of the unbalanced loads; and whenever there is a low impedance path provided for it, the percentage of voltage unbalance will be reduced.

Figure 4-20 (C) shows that the generator neutral and load neutral are the same, because they are connected directly by the fourth conductor, or ground. It shows also how the fundamental generated voltage in each phase is affected by its load and winding reactance so that the final and actual terminal voltage for each phase is quite different from the fundamental e. m. f.

The percent of phase terminal voltage unbalance may be found by:

$$\text{Percent unbalance} = \frac{100 \times \text{maximum deviation from average}}{\text{average}}$$

where the average voltage is:

$$\frac{120 + 134 + 131}{3} = 128 \text{ volts.}$$

Maximum deviation from average is 128 - 120 = 8 volts. Unbalance is

$$\frac{100 \times 8}{128} = 6.25 \text{ percent.}$$

NOTE: Does the voltage unbalance and phase displacement exceed the specification limits?

The above example illustrates the disadvantage of having the voltage control on only one phase in that it will allow excessively high voltages on the unregulated phases when the regulated phase is heavily loaded. On the other hand, if the regulated phase is lightly loaded, the unregulated phase voltages will be below normal. Single-phase sensing does have the advantage of providing close voltage regulation on one phase of the system in order to accommodate voltage-sensitive loads. Unbalanced loading, however, generally results in greater voltage unbalance with single-phase sensing than when the average voltage of the three phases is regulated.

Problem 3. This problem involves the same system used in problem 2, except that a three-phase sensing voltage regulator and a load contactor are added. Figure 4-21 (A) will be used as reference for this problem.

Before the load is connected, the terminal voltage is the no-load voltage of 120 volts per phase. When the load contactor is closed, there will be a transient flow of current equal to the no-load voltage divided by the total impedance of each phase.

$$I_A = \frac{E_{OA}}{Z_A} = \frac{120 \angle 0^\circ}{5 + j3} = \frac{120 \angle 0^\circ}{5.84 \angle 31^\circ} = 20.6 \angle -31^\circ$$

$$I_B = \frac{E_{OB}}{Z_B} = \frac{120 \angle -120^\circ}{8 + j3} = \frac{120 \angle -120^\circ}{8.54 \angle 20.6^\circ} = 14.1 \angle -140.6^\circ$$

$$I_C = \frac{E_{OC}}{Z_C} = \frac{120 \angle 120^\circ}{10 + j3} = \frac{120 \angle 120^\circ}{10.4 \angle 16.7^\circ} = 11.5 \angle 103.3^\circ$$

The terminal voltages will be equal to line current times load impedance.

$$V_{OA} = 5 \times 20.6 \angle -31^\circ = 103 \angle -31^\circ$$

$$V_{OB} = 8 \times 14.1 \angle -140.6^\circ = 112 \angle -140.6^\circ$$

$$V_{OC} = 10 \times 11.5 \angle 103.3^\circ = 115 \angle 103.3^\circ.$$

The average of these three voltages is sensed by the voltage regulator.

$$E_{AV} = \frac{103 + 112 + 115}{3} = 110 \text{ volts.}$$

As the regulator is adjusted to maintain an average voltage of 120 volts, it will increase the field excitation in order to bring the average terminal voltage up to 120 volts. This may be approximated for instructional purposes only as an additional 10-volt increase on each phase voltage (true solution involves more complicated mathematics). The three terminal voltages will now become

$$V_{OA} = 113 \angle -31^\circ$$

$$V_{OB} = 122 \angle -140.6^\circ$$

$$V_{OC} = 125 \angle 103.3^\circ.$$

The percentage of unbalance will be approximately:

$$\frac{100 \times (120 - 113)}{120} = \frac{700}{120} = 5.84 \text{ percent.}$$

The current in the ground neutral will be the vector sum of the phase currents.

$$I_A = 20.6 \angle -31^\circ = 17.6 - j10.6$$

$$I_B = 14.1 \angle -140.6^\circ = -10.9 - j8.95$$

$$I_C = 11.5 \angle 103.3^\circ = -2.64 + j11.2$$

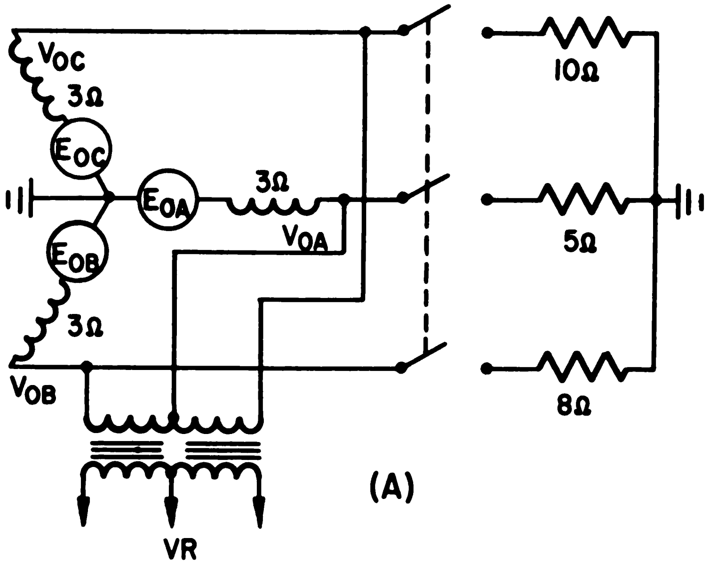
$$I_N = 9.29 \angle -64^\circ = 4.06 - j8.35 \text{ amp.}$$

Figure 4-21 (B) shows the difference between the fundamental e. m. f. and terminal voltage of each phase. Remember that this diagram represents a system whose voltage control is based on the sensing of the average of the three-phase voltages. Figure 4-20 (B) represented a system whose voltage control was based on the voltage of only one phase. Note the significant difference between the two.

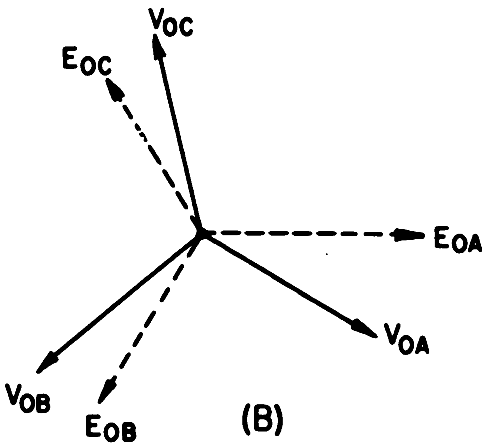
The preceding problem illustrates a principle of voltage control based upon the average of the three circuit voltages. On unbalanced loading, the average voltage will be maintained at the adjusted value even though none of the single-phase voltages are equal to the adjusted value. Note also that the amount of unbalance is somewhat reduced.

Problem 4. Considering the same system, determine what would occur should the neutral (ground) wire become open under an unbalanced load condition.

NOTE: In a three-wire wye system, the solution is simplified by use of the Millman theorem.



(A)



(B)

Figure 4-21.—(A) Four-wire unbalanced wye, using three-phase sensing voltage control; (B) difference of fundamental e. m. f. and terminal voltage.

With the power contactor open, the terminal voltage will equal the no-load voltage and will be maintained at a value of 120 volts per phase by the regulator.

$$V_{OA} = E_{OA} = 120 \underline{/0^\circ} = 120 + j0.0$$

$$V_{OB} = E_{OB} = 120 \underline{/-120^\circ} = -60 - j104.0$$

$$V_{OC} = E_{OC} = 120 \underline{/120^\circ} = -60 + j104.0.$$

When the line contactor is closed, the voltage shift of the neutral may be determined by the formula:

$$V_{ON} = \frac{E_{OA}Y_1 + E_{OB}Y_2 + E_{OC}Y_3}{Y_1 + Y_2 + Y_3}$$

where Y_1 = Admittance of phase A

Y_2 = Admittance of phase B

Y_3 = Admittance of phase C

$$Y = \frac{1}{Z} = \frac{1}{R + jX} = \frac{R}{Z_2} - j\frac{X}{Z_2}$$

Impedances:	Admittances:
$Z_A = 5 + j3 = 5.84;$	$Y_1 = \frac{5}{34} - j\frac{3}{34} = 0.147 - j0.088$
$Z_B = 8 + j3 = 8.54;$	$Y_2 = \frac{8}{73} - j\frac{3}{73} = 0.110 - j0.041$
$Z_C = 10 + j3 = 10.4;$	$Y_3 = \frac{10}{109} - j\frac{3}{109} = 0.092 - j0.0275$
	Summation of Y's $= 0.349 - j0.1565$

$$E_{OA}Y_1 = (120 + j0)(0.147 - j.088) = 17.60 - j10.60$$

$$E_{OB}Y_2 = (-60 - j104)(0.110 - j.041) = -10.88 - j8.96$$

$$E_{OC}Y_3 = (-60 + j104)(0.092 - j.0275) = -2.65 - 11.20$$

Summation of EY's $= 4.07 - j8.36$

$$V_{ON} = \frac{4.07 - j8.36}{0.349 - j0.1365} = 18.0 - j16.6.$$

Solution for line currents:

$$I_A = (E_{OA} - V_{ON})\, Y_1$$

$$= [(120 + j0) - (18 - j16.6)]\,(0.147 - j0.088)$$

$$= (120 - 18 + j16.6)\,(0.147 - j.088)$$

$$= (102 + j16.6)\,(0.147 - j.088)$$

$$= 16.46 - j6.54 = 17.7\ \underline{/-21.7^\circ}$$

$$I_B = (E_{OB} - V_{ON})\, Y_2$$

$$= [(-60 - j104) - (18 - j16.6)]\,(0.110 - j.041)$$

$$= (-60 - j104 - 18 + j16.6)\,(0.110 - j.041)$$

$$= (-78 - j87.4)\,(0.110 - j.041)$$

$$= -12.16 - j6.4 = 13.7\ \underline{/-152.2^\circ}$$

$$I_C = (E_{OC} - V_{ON})\, Y_3$$

$$= [(-60 + j104) - (18 - j16.6)]\,(0.092 - j.0275)$$

$$= (-60 + j104 - 18 + j16.6)\,(0.092 - j.0275)$$

$$= (-78 + j120.6)\,(0.092 - j.0275)$$

$$= -3.85 + j13.24 = 13.8\ \underline{/106.2^\circ}$$

The transient value of terminal voltage may be determined by multiplying each phase current by the load impedance of each phase.

$$V_{NA} = 5 \times 17.7\ \underline{/-21.7^\circ} = 88.5\ \underline{/-21.7^\circ}$$

$$V_{NB} = 8 \times 13.7\ \underline{/-152.2^\circ} = 110.0\ \underline{/-152.2^\circ}$$

$$V_{NC} = 10 \times 13.8\ \underline{/106.2^\circ} = 138.0\ \underline{/106.2^\circ}.$$

The average of these transient voltages is:

$$\frac{88.5 + 110 + 138}{3} = 112 \text{ volts.}$$

The regulator reacts to bring the average voltage up to the desired level which, for approximation only, will be an additional 8 volts per phase. The steady-state terminal voltages will now be:

$$V_{NA} = 96.5 \underline{/-21.7^\circ}$$

$$V_{NB} = 118.0 \underline{/-152.2^\circ}$$

$$V_{NC} = 146.0 \underline{/106.2^\circ}.$$

The percentage of voltage unbalance will be:

$$\frac{100 \times (146 - 120)}{120} = \frac{26}{120} = 21.6 \text{ percent.}$$

Comparing this magnitude of unbalance with that obtained in problem 3, it becomes evident that, whenever there is a neutral conductor, the percentage of voltage unbalance will be greatly reduced. If there were no internal impedance in the voltage source, the voltage unbalance could be reduced to zero under all load conditions by use of the grounded neutral.

In all the examples shown it will be noted that the voltage on the lightly loaded phases will be excessive, while that of the heavier loaded phase will be below normal. Operation of additional loads, both single-phase and polyphase, will be seriously affected by this unbalance.

NOTE: The problems presented in this section are intended only as a teaching aid in order to show the effects of unbalance under various circuit conditions. The voltages and degree of unbalance should not be accepted as being the exact values that would result under actual conditions. In order to take into account the transformer action that exists between phases of the generator, which alters terminal voltage, the solution would have to involve the use of positive, negative, and zero sequence components of an unbalanced circuit.

Correction for Unbalanced Load Conditions

The best correction for unbalanced load conditions is to prevent this condition from occurring in the first place.

Considerable effort is put forth by aircraft electrical system designers to insure that the minimum possible degree of unbalance exists under all flight conditions.

However, when the operative loads of the aircraft cannot be distributed on the polyphase system so as to maintain the desired voltage balance, dummy loads are placed on the lightly loaded phases in order to balance the total volt-amperes. This is especially true for inverters, which are more susceptible to unbalance than the larger a-c generators.

The electrical system of the AD-6, F7U-3, and F2H-3 are examples of the use of dummy loads to correct for voltage unbalance of the inverters.

QUIZ

1. When representing currents in an alternating-current circuit with the double subscript notation, the notation
   a. represents the current existing between two points
   b. represents the current's identity and direction
   c. represents an instantaneous value of current
   d. indicates that it is a polyphase current.

2. The phase displacement between line current and line voltage in a wye-connected system is due to the
   a. manner in which the phases are connected
   b. load being reactive
   c. type of load and manner of connection
   d. 30° difference between line and phase voltages.

3. Which of the following formulas apply in a three-phase balanced system?
   a. $E_L = E_C \sqrt{3}$; and $I_L = I_C$ in a delta connection
   b. $E_L = E_C$; and $I_L = I_C \sqrt{3}$ in a wye connection
   c. $E_L = E_C$; and $I_L = I_C$ in a delta connection
   d. $E_L = E_C \sqrt{3}$; and $I_L = I_C$ in a wye connection.

4. In a balanced wye-connected system, as the power factor decreases,
   a. E_L and I_L will become more nearly in phase
   b. E_L and E_C will become more nearly in phase
   c. the angle between E_C and I_C will decrease
   d. the angle between E_L and I_C will change.

5. Admittance in an a-c circuit is equal to

   a. $Y = \frac{1}{R \pm JX}$

   b. $Y = \frac{I}{R} \pm J\frac{1}{X}$

   c. $Y = \frac{1}{G \pm JB}$

   d. $Y = \frac{1}{G} + \frac{1}{B}$

6. In a parallel a-c circuit the total admittance is equal to

   a. $Y_T = \frac{1}{Z_1 + Z_2}$

   b. $Y_T = Y_1 + Y_2$

   c. $Y_T = \frac{1}{G_1 + G_2} \pm J\frac{1}{B_1 + B_2}$

   d. $Y_T = \frac{1}{R_1 + R_2} \pm J\frac{1}{X_1 + X_2}$

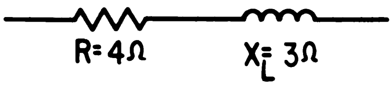
7. In the drawing below,

   a. $Y = \frac{1}{4} - J\frac{1}{3}$ and $I = E \times Y$

   b. $Y = \frac{1}{4 + J3}$ and $P = \frac{I^2}{Y}$

   c. $Y = 3 - J4$ and $E = I \times Z$

   d. $Y = 0.12 + J0.16$ and $I = E \times Y$



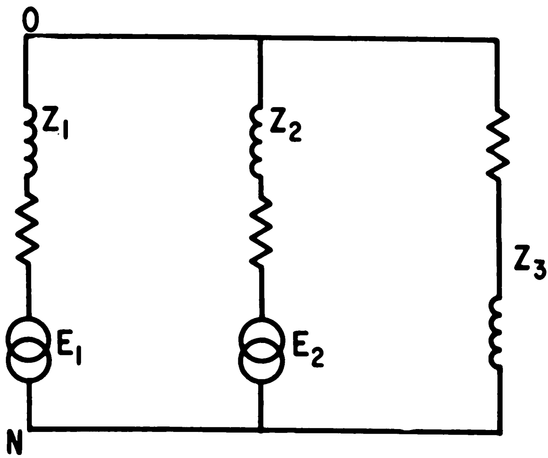
8. In the drawing below,

a. $E_{ON} = \dfrac{I_1 + I_2 + I_3}{Z_1 + Z_2 + Z_3}$

b. $E_{ON} = \dfrac{I_1 + I_2 - I_3}{Y_1 + Y_2 - Y_3}$

c. $E_{ON} = \dfrac{I_1 + I_2 + I_3}{Y_1 + Y_2 + Y_3}$

d. $E_{ON} = I_3 Y_3$.



9. One of the effects of an unbalanced load on a three-phase generator is that the

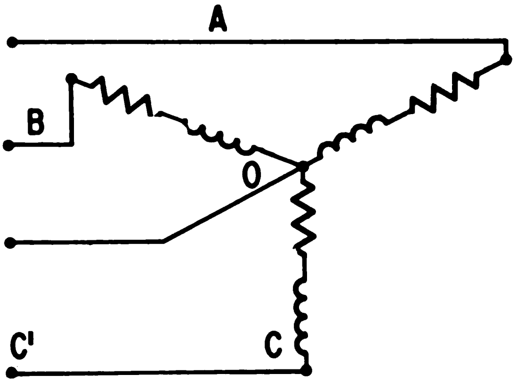
a. phase voltages generally will not be 120° apart

b. power factor will decrease

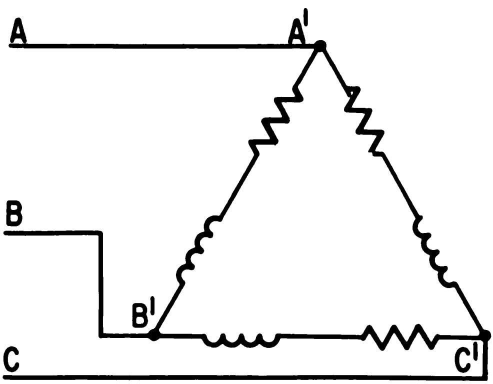
c. line voltages will decrease

d. impedance of the line conductors will decrease

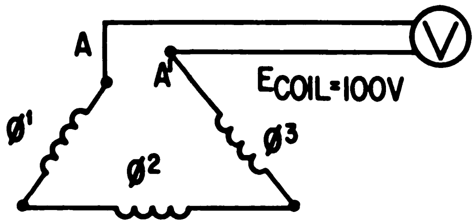
10. With a delta-connected generator,
   a. $E_L = E_C$; and $I_L = I_C$
   b. E_L and I_L are displaced by 30° when $\underline{/\theta}$ is 0°
   c. $E_L = E_C\sqrt{3}$; and $I_L = I_C$
   d. phase voltage of the generator and phase voltage of the load are the same.
11. In an unbalanced four-wire wye-connected load
   a. the volt-amperes of each phase must be the same
   b. current will normally flow in the neutral conductor
   c. the current in the neutral conductor will be $\sqrt{3}$ times phase current
   d. line current will be $\sqrt{3}$ times phase current.
12. In a balanced delta-connected system
   a. $I_C = E_C \times Y_C$
   b. $I_C = I_L$
   c. $I_L = E_L \times Y_T$
   d. $I_L = \dfrac{E_L}{Z_T}$.
13. In a balanced resistive wye-connected system $\underline{/\theta}$ exists between
   a. E_L and I_L
   b. E_L and E_C
   c. I_C and E_C
   d. I_C and I_L
14. If $Z = 3 + j4$, then
   a. $G = 0.16$ mho
   b. $B = +j10.16$ mho
   c. $Y = 0.12 - j0.16$ mho
   d. $I = 12 - j16$ amps.
15. When Y for a circuit is $5 + j12$ mhos, its
   a. $Y = 17$ mhos
   b. $R = 0.0295$ ohms
   c. $G = 12$ mhos
   d. $Z = 0.770$ ohms.
16. In the drawing below,
   a. $I_{BO} + I_{AO} = I_{CO}$
   b. $E_{AB} = E_{AO} + E_{OB}$
   c. $I_{BO} + I_{CO} = I_{OA}$
   d. $E_{AB} + E_{BC} = E_{CA}$.



17. In the drawing below, $I_{AA'}$ equals
    a. $I_{A'B'}$
    b. $I_{A'C'}$
    c. $I_{A'B'} + I_{A'C'}$
    d. $I_{B'A'} + I_{C'A'}$.



18. In the drawing below, the voltmeter reads closure voltage of zero. If coil No. 1 is reversed, the voltmeter will read
    a. zero
    b. 100 volts
    c. 200 volts
    d. 173.2 volts.



19. In a wye-connected four-wire balanced system
    a. E_L and I_L are displaced by 0°

    b. $E_{AO} = 0$

    c. E_L and I_L are displaced by 12r˝

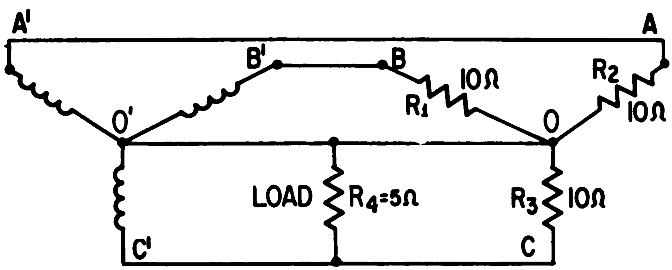
    d. $I_{OO'} = 0$.

20. In the drawing below,
    a. $I_{OO'} = I_3 + I_4$

    b. the generator can not be operated at normal KVA rating

    c. $I_{OO'} = I_3$

    d. the generator KVA rating has been increased by the connection of $R4$.

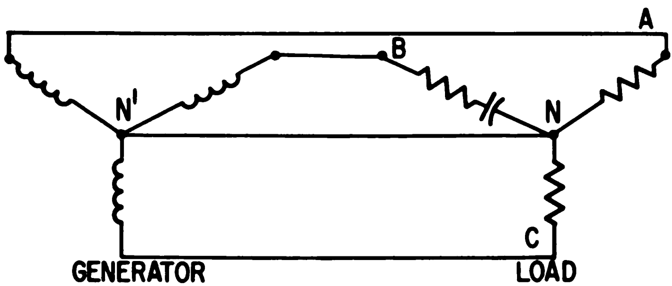


21. In the drawing below, if line N became open circuited, the
    a. percent of unbalance would increase

    b. phase voltages would remain 120° displaced

    c. phase voltages would remain equal

    d. phase currents would be equal.



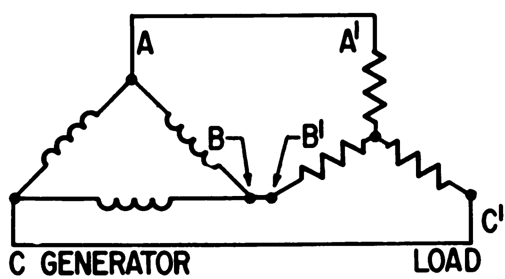
22. In the drawing below,

    a. line current is equal to coil current in the generator

    b. coil voltage of the generator and coil voltage of the load are equal

    c. coil current and voltage of the generator are in phase

    d. line current is equal to coil current in the load.



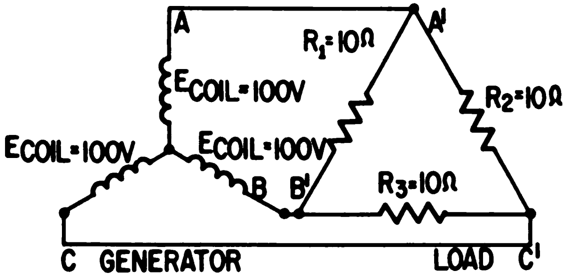
23. In the drawing below,

    a. I_L = 30 amps

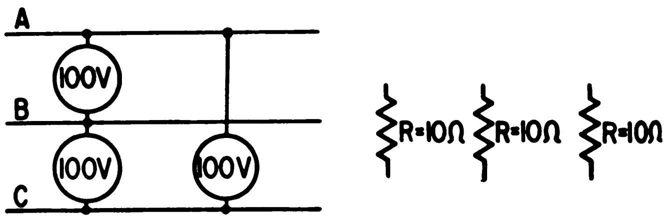
    b. E_L = 100 volts

    c. I_L = 17.32 amps

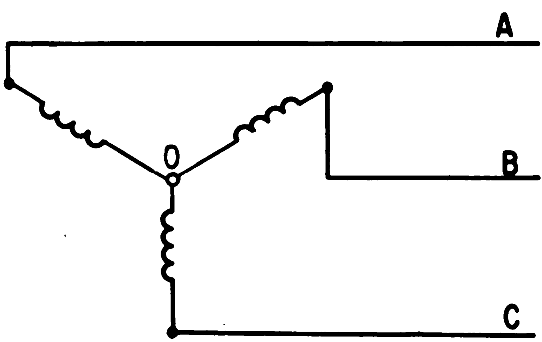
    d. E_{R3} = 100 volts.



24. Given: Three-phase power supply and three identical noninductive resistors in the drawing below. If the resistors are connected in
    a. wye, true power will be 3,000 watts
    b. delta, true power will be 1,000 watts
    c. wye, the power would be the same as if in delta
    d. delta, the power would be three times that of wye.



25. In the drawing below,
    a. E_{AO} is 120° from E_{OC}
    b. E_{OB} is 120° from E_{OA}
    c. E_{CO} is 120° from E_{OB}
    d. E_{OA} is 120° from E_{CO}



CHAPTER 5

MAGNETIC AMPLIFIERS

The magnetic amplifier, a rising competitor of the vacuum tube in power and control applications, is rapidly becoming an important device in electrical and electronic equipment. Amplifiers of this type have many features which are desirable in naval aircraft equipment. They may be used to provide large amounts of either power or voltage gain. They are rugged and reliable, require no cathode heating and no high d-c operating potentials, and are relatively simple in construction and operation.

Until comparatively recent times, magnetic control has had little application in aircraft electronic equipment since existing units were slow in response and were of excessive size and weight. But with the development of new and improved magnetic materials, there has been a parallel development of magnetic circuits for tubeless amplification; and many of these units are now employed in automatic pilots, static a-c voltage regulators, and in associated test equipment.

Magnetic amplifiers are devices which control the degree of magnetization in the core of a coil in order to control the current and voltage at the load or output. One of the oldest forms of magnetic amplifiers, the saturable reactor, contains at least two coils wound on a common core made of magnetic material. A d-c control voltage is applied to one of the coils; and the resulting current serves to modify the reactance of the second winding by causing magnetic saturation of the common core. The second coil is a series element in the a-c load circuit

so that current variations take place in the load in accordance with those made in the control voltage. In more complex magnetic amplifiers, the input, or control signal, may be either d-c or a properly phased a-c voltage.

In addition to saturable reactors, there are numerous types of magnetic units in use, including voltage regulators, low- and high-frequency amplifiers, and servomotor controllers. The purpose of this discussion is to present the operating principles of these devices and to give representative examples of magnetic circuits employed in aircraft electrical equipment. Before continuing with this chapter, it is suggested that you become familiar with the fundamentals of magnetics. A suggested reference is the training course *Basic Electricity,* NavPers 10086.

BASIC PRINCIPLES OF OPERATION

Basically, a magnetic amplifier consists of a controlled variable inductance in series with an a-c power supply and a load resistor. The control action involves changes in the magnetic permeability of the inductance coil with resulting changes in inductance, inductive reactance, and impedance of the load circuit. As a result, changes are made in the current flowing in the load and the voltage developed at the output.

As explained in *Basic Electricity,* inductance (often called electrical inertia) is the primary electrical property of any coil. The inductance value of a particular coil is determined by its physical characteristics; and in general, it can be increased in an air-core winding, for example, by inserting a core made of magnetic material. The reason for this effect can be seen by considering the factors that influence inductance as expressed in the following formula:

$$L = \frac{1.256\ N^2 A \mu 10^{-8}}{l}$$

where L = inductance in henries
N = number of turns
A = area of the core in square centimeters
μ = permeability of the core material
l = length of the core in centimeters.

The permeability of a substance is a measure of the ease with which it conducts magnetic lines of force when compared with some convenient reference material such as air. When air is taken as the standard, its permeability is one (1). On this basis, the permeability values of ferromagnetic materials, such as iron and steel, range from approximately 60 to 6,000.

From the inductance equation, it can be seen that the inductance of an air-core winding can be increased enormously by inserting a core made of ferromagnetic material. Thus, if an iron-alloy core with a permeability of 1,000 is inserted, the inductance becomes 1,000 times greater than the former value with an air core. The effect of this change when the coil is used as a series current limiting element can be shown by means of a diagram.

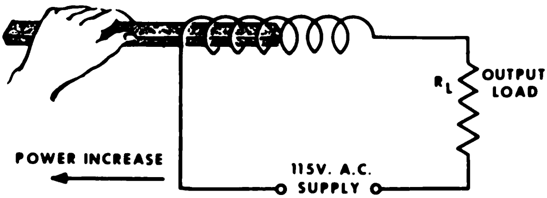


Figure 5-1.—Varying inductance manually.

A very simple circuit is shown in figure 5-1 to illustrate the fundamental control process. The iron core is moved in and out of the winding to alternately increase and decrease the effective permeability. This varies the inductance and hence the inductive reactance in series with the load resistor. When the core is completely within the winding, the inductive reactance is maximum and the voltage drop across the coil is a large fraction of the applied voltage. As a result, the load voltage is low and the current flow is minimum.

Removing the core from the coil (fig. 5-1) lowers the inductance, decreases the inductive reactance, and permits the current to rise and the voltage drop across the load resistor to increase proportionately. By means of this simple arrangement, a comparatively small amount of energy is sufficient to control the output of a source

with a possible rating of several horsepower; and for this reason, the circuit functions as a magnetic amplifier.

In more practical forms of magnetic control, large a-c sources are controlled by a method which gives much the same result as the circuit shown in figure 5-1. In these circuits, the series winding has a fixed magnetic core; the core's permeability is varied by saturating or unsaturating the material with a relatively small control current.

When the control current is increased sufficiently to saturate the core, the inductance is lowered, and the reactance is then about the same as that of an air-core winding under similar conditions. With a reduction in control current, the core becomes unsaturated, the reactance increases, and the output current and voltage decrease. The principal features of this process can be made clear by reviewing some of the basic magnetic concepts and by considering the magnetization curve of a typical core material.

It will be recalled that when current flows in a coil, there is a resulting magnetomotive force, which in the magnetic circuit is comparable to applied voltage in the electric circuit. The strength of the magnetomotive force is determined by the ampere turns. The ampere turns is the current in the coil times the number of turns in the coil.

The magnetomotive force produces magnetic flux consisting of closed lines of force that are comparable to current in the electric circuit. The quantity of flux, or the total number of lines, varies directly with the amount of magnetomotive force but inversely with the reluctance of the path comprising the magnetic circuit. Magnetic reluctance, the quantity analogous to electrical resistance, is a property of the material in which the flux lines are established; and in the case of the electromagnet, or coil, the reluctance value is determined principally by the nature of the core.

The reluctance of an air core remains constant regardless of the applied magnetomotive force and the quantity of flux. However, when a ferromagnetic substance is used as a core material, the reluctance is no longer constant. Instead, as the magnetizing current begins to flow, the reluctance is low and the resulting flux is very high compared with the flux existing in an air-core coil under

similar conditions. As the magnetizing current is increased, the reluctance increases and the rate-of-flux-increase falls off.

When the current reaches a certain value, depending on the core material, the reluctance increases very rapidly, its value approaching that of air. In this condition, further increase of the magnetizing current produces a comparatively small increase in total flux and the core is said to be saturated.

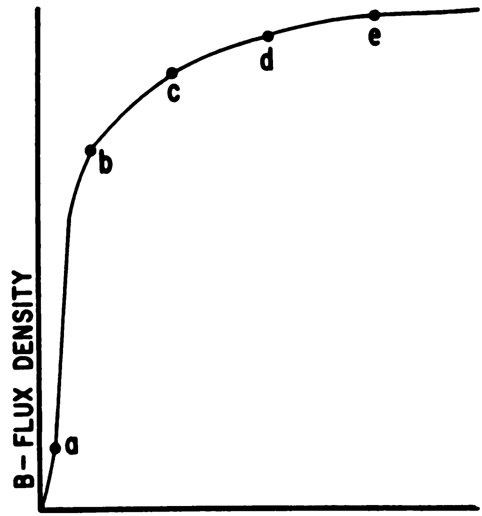


Figure 5-2.—Magnetization curve.

The condition of saturation and the resulting effects on permeability and inductance can be illustrated by the curve shown in figure 5-2. In this graph, the flux density (B) in a typical material is plotted against the magnetizing force (H), which is proportional to applied ampere turns. The ratio of the two values, of B/H, is equal to the permeability of the material. And from the shape of the curve, it is seen that permeability is not constant but has different values for different amounts of magnetizing force.

From point *a* to point *b*, (fig. 5-2), the curve rises steeply in what is substantially a straight line. In this region, the permeability is high and the coil has a large

inductance value. From point *b* to point *d*, a small change in H produces a much smaller change in flux density than on the linear part of the curve. Here, the permeability is lower and the inductance is correspondingly smaller. From point *d* to point *e* and beyond, the curve is almost flat, indicating a very small increase in B as H is increased. In the latter condition, the core is saturated and the inductance is minimum.

Since the basic control action of the magnetic amplifier depends upon changes in inductance, the region between points *b* and *d* (fig. 5-2) represents the ideal operating range. If the action is such that control signals swing the magnetization about point *c*, comparatively small changes in input result in large variations in output-circuit impedance. In most modern applications of magnetic amplifiers, the saturation method is used since it simplifies the operation, permits faster response, and eliminates moving parts.

FUNDAMENTALS OF MAGNETIC-AMPLIFIER CIRCUITS

The various forms of magnetic amplifiers used in practical applications have certain circuit elements in common, including d-c or a-c control windings; dry-disk rectifiers; special forms of magnetic cores; biasing coils; and feedback circuits. Among the processes of importance are hysteresis effects and the actions determining speed of response of the amplifier.

In this section, these components and processes are introduced by considering first a basic circuit to illustrate the fundamental method of control. This circuit is then developed into more complex form by addition of components which increase or improve the response.

The Basic Circuit

The basic arrangement of components for controlling a-c load power by means of a control coil is illustrated in figure 5-3. Two windings are required, both of which are wrapped on a common core. The control winding, shown on the left, is supplied from a d-c source, and the control current is adjusted by a potentiometer. It is the purpose

of the control current to establish a unidirectional flux in the core with an intensity determined by the d-c ampere turns of the control circuit. The second coil, the load winding, is connected in series with an a-c power source and the load resistance, which in this case is a lamp.

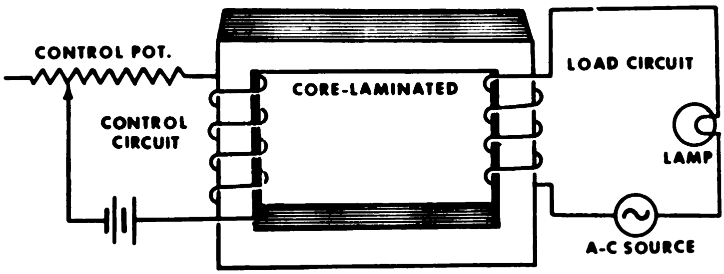


Figure 5-3.—A simple magnetic amplifier.

With the circuit (fig. 5-3) operating on the knee of the magnetization curve, a small increase in control current lowers the inductance of the load winding. This occurs because the degree of magnetization is shifted to a point on the curve where the slope approaches the horizontal, and the permeability of the core material is thereby decreased. As a result, the inductive reactance of the load winding is lowered; the total load-circuit impedance falls off; and the load current rises, causing the power developed in the load to increase.

If control current increases enough to saturate the core completely, the load winding reactance drops nearly to zero, leaving the resistances of the winding and of the load as the principal current limiting elements. In this condition, maximum supply voltage is applied to the load, and the lamp then glows at maximum brightness.

On the other hand, decreasing the control current causes an increase in the reactance of the load winding since the operating point is moved toward the steep part of the curve, thereby increasing the permeability. With the coil at maximum inductance, there is a corresponding minimum value of load current and consequently minimum load power. Thus, for a small change in control power,

the magnetic action produces a large change in load power, so that the device functions as an amplifier.

Although the explanation just given illustrates the basic method of controlling core permeability, the arrangement shown in figure 5-3 is seldom used because it is a very inefficient magnetic amplifier. Transformer action takes place so that energy is coupled from one winding to another. The alternating flux resulting from secondary, or load current, induces voltage into the control winding. If the latter coil has a large number of turns, the induced voltage may become excessive and may even break down the insulation. Even if the coupled voltage is small, the control circuit acts as a low-resistance winding and dissipates a considerable amount of energy that would normally be applied to the output.

It is possible to reduce the losses resulting from unwanted coupling by inserting an isolating impedance in the form of an inductance placed in series with the control winding; or losses may be minimized by the use of a three-legged core. The latter method is described in the following pages.

THREE-LEGGED MAGNETIC CORES.—A more satisfactory circuit arrangement results when the basic amplifier is modified as shown in figure 5-4. This device, called a saturable reactor, is often employed for controlling large amounts of alternating current. It contains a three-legged core with an a-c winding on each outer leg and a d-c control winding on the center leg. The chief advantage of this core structure is that alternating flux components produced by currents in the load windings are balanced out in the center leg and do not affect the control circuit. However, this desirable condition exists only if the two a-c coils have equal numbers of turns and are wound so that the flux lines oppose, as indicated by the dotted line in the drawing.

While alternating flux does not pass effectively through the center leg (fig. 5-4), the two components add along the path through the outer legs of the core as indicated by the broken lines. The drawing also shows that the control current produces a magnetic flux (represented by solid lines) that magnetizes the entire core of each load winding. Thus, while the d-c coil can influence the operation of the load circuit, there is no coupling of energy by

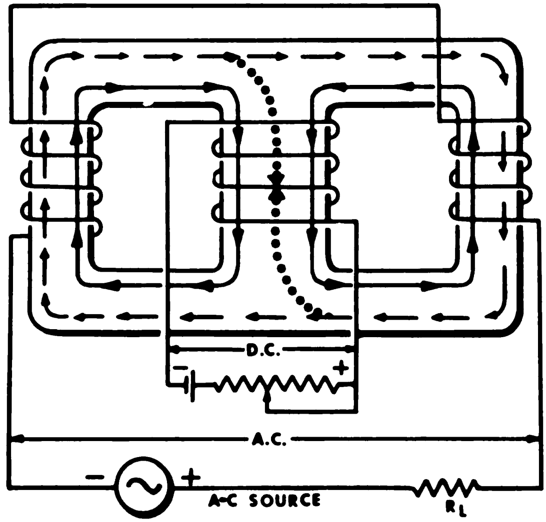


Figure 5-4.—Magnetic amplifier with three-legged core.

transformer action from the load circuit to the control winding.

During normal operation, variations of the control current result in corresponding changes in core permeability; and this, in turn, readjusts the inductive reactance in series with the load. Hence, as far as the control process is concerned, the operation of the saturable reactor is similar to that of the basic magnetic amplifier.

MAGNETIC AMPLIFIERS WITH HALF-WAVE RECTIFIERS.—The operation of the simple amplifier (fig. 5-3) is inefficient; and it has an additional disadvantage in that relatively large amounts of control current are required. This is because the control ampere turns must overcome the effects of the comparatively large a-c load current, which establishes sinusoidally varying magnetic flux in the core. The intensity and direction of the magnetic field produced by load current when no control current is flowing can be shown better by a hysteresis curve, as in figure 5-5.

The interpretation of the hysteresis curve for typical core materials is given in detail in *Basic Electricity*, NavPers 10086. It is sufficient here to note that the

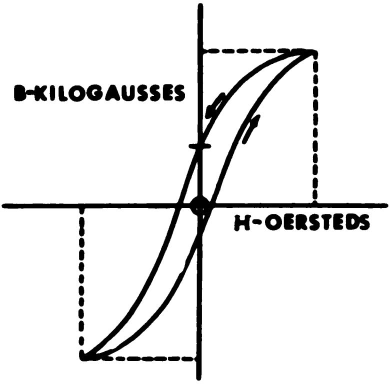


Figure 5-5.—Hysteresis curve.

magnetizing force (expressed in oersteds) varies along the horizontal axis of the graph in accordance with the a-c current applied by the power source. As a result, the magnetic flux density (in gausses) has values both above and below the zero level (fig. 5-5), indicating a regular change in direction of the flux lines. Thus, in the operation of the magnetic amplifier, the flux created by the load current impedes the control flux during one half cycle and aids it during the other.

In order to produce sufficient flux to balance out the oscillating flux of the load currents, the ampere turns provided by the control winding must equal the ampere turns of the load windings. In addition, sufficient extra control magnetizing force is needed to set the operating point at the desired place on the magnetization curve. The combination of these two demands results in a very ineffective amplifier since the control-circuit ampere turns must exceed the ampere turns of the load circuit. This difficulty is overcome by using rectifier units. These units eliminate the unwanted currents and permit self-saturating operation of the amplifier.

A more efficient magnetic amplifier is shown in figure 5-6. A half-wave rectifier (usually the dry-disk type), inserted in the load circuit, permits current to flow in one direction only. Because of the unidirectional load current, one-half of the formerly oscillating flux is eliminated; and the remaining field may either assist or oppose the control

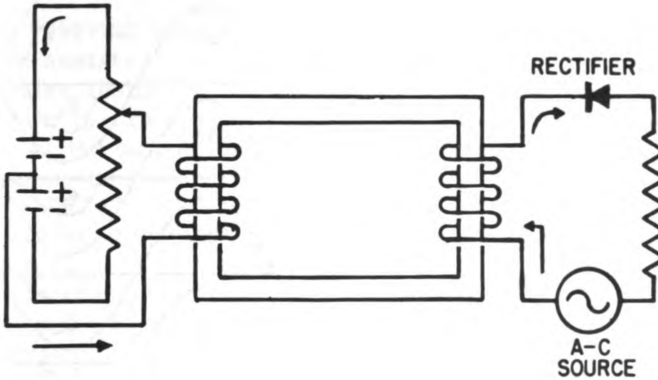


Figure 5-6.—Magnetic amplifier with half-wave rectifier.

flux, depending on the position of the arm of the control potentiometer. The arrows in the drawing indicate the direction of electron flow. In the case illustrated, it can be seen by applying the left-hand rule for determining the direction of the magnetic fields, that the load flux assists the control flux in saturating the core. By moving the arm of the control potentiometer toward the negative end, the fields would then be made to oppose. In either case, however, a more effective amplifier is provided since less control power is required for a given amount of output power.

The action of the circuit with the rectifier limiting the load current to unidirectional flow can be interpreted as a form of feedback. Since the entire feedback effect takes place within the magnetic circuit comprised of the core and is accomplished without the use of additional coils or control elements, it is classified as internal feedback. The use of additional circuit elements to provide external feedback is discussed in detail in a subsequent part of the chapter. Consider first, the process by which the load circuit is made to assist the control action in the self-saturating magnetic amplifier.

SELF-SATURATING MAGNETIC AMPLIFIER.—The operation of the self-saturating amplifier can be understood by use of a magnetization curve in which the hysteresis effect is eliminated as in figure 5-7. Point 1 on the curve indicates the condition of the control flux when the

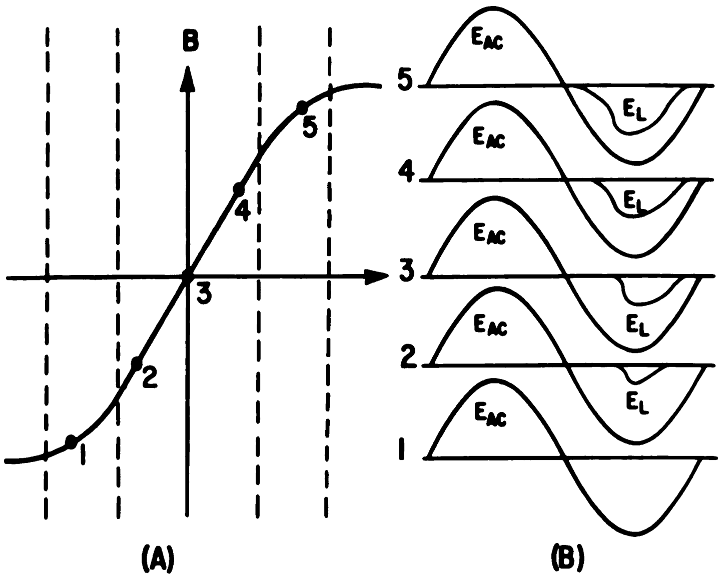


Figure 5-7.—Operation of self-saturating magnetic amplifier.

potentiometer (fig. 5-6) is set to apply a negative control voltage. Under this condition, the control flux is in opposition to the flux resulting from load current. If the amplitude of the load current is such that the total core flux varies along the curve from point 1 to point 4, the impedance of the secondary remains large; and the voltage drop across the load resistor is very low. The relation of the applied voltage to the load voltage is shown in the lower drawing of figure 5-7 (B).

When the potentiometer arm is moved toward the positive end, the control current flows in the same direction as before but with less amplitude. The rectified load current then varies the core flux between points 2 and 5 on the magnetization curve (fig. 5-7). Under this condition, partial saturation of the core results, and the output waveform resulting is shown in drawing 2 of figure 5-7 (B).

As the potentiometer is moved nearer the positive end, placing the operating point to position 3, the control current is then zero. The resulting waveform at the output is that shown in drawing 3 of figure 5-7 (B). At position 4, the control voltage and current are reversed with

respect to the original direction, producing a corresponding reversal of control flux. In this condition, the control flux assists the load flux and saturation is reached at an earlier instant in the a-c cycle. The resulting output is shown in drawing 4; while drawing 5 of the same figure shows the output current when the control voltage is made even more positive.

EFFECTS OF HYSTERESIS ON OPERATION.—In the preceding discussion of the basic magnetic amplifier, the magnetic characteristics of the core material are largely neglected, and emphasis is placed on the function of the fundamental components. In order to understand fully the operation of self-saturating amplifiers, it is necessary to consider the shape of the hysteresis loop and its significance in circuit operation.

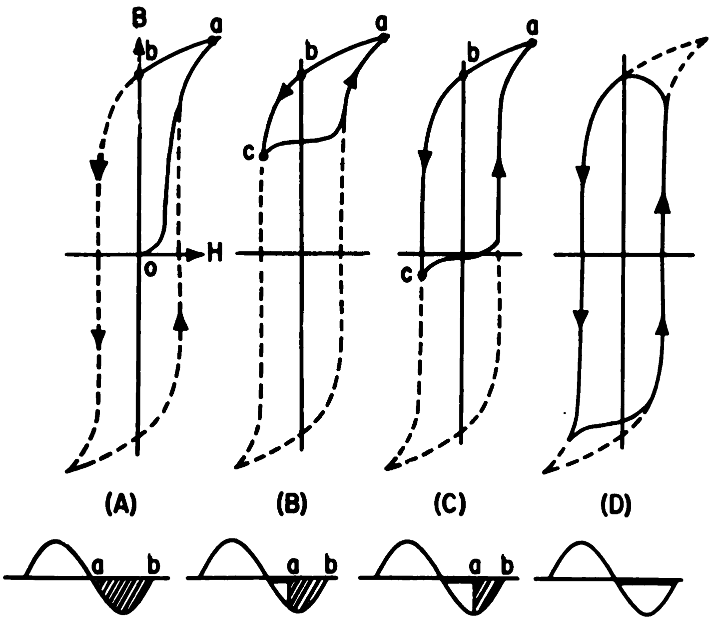


Figure 5-8.—Operation of magnetic amplifier showing effects of hysteresis.

The B-H curve of a typical magnetic material is shown in (A) of figure 5-8. Assume that this material is used as

the core of a magnetic amplifier of the type illustrated in figure 5-6. The amplifier has two distinct periods of operation: the interval during which the rectifier conducts is called the operating period; while the nonconducting half cycle of applied voltage is called the control period. The solid line of the hysteresis loop in (A) indicates the variation of flux within the core when the control voltage is set at zero so that no control current flows. During the operating period, the load current, which is assumed to be of sufficient amplitude to saturate the core, swings the flux from point *o* on the curve to point *a*, the saturation value.

At the end of the first operating period, the degree of magnetization returns, not to the original starting point, but to point *b* (fig. 5-8) because of retentivity of the core. (This value on the graph is called the remanence point. It indicates the amount of flux left in the material when the magnetizing force is removed and is also a measure of the usefulness of the material to serve as a permanent magnet.) The part of the hysteresis loop shown in broken lines in (A) of figure 5-8 represents the further change in magnetization that would occur if the magnetizing current were permitted to reverse in direction to complete the normal hysteresis graph.

The core remains magnetized at the remanence point during the control period of the amplifier. During each following half-cycle operating period, the material saturates immediately; and the load current is maximun since no control is exercised. The output waveform for this condition of the control circuit is shown directly under the loop drawing (A) of figure 5-8.

Figure 5-8 (B) shows the operation when a small control current is flowing in a direction to cause the control flux to oppose the load-current flux. The initial change in core magnetization is similar to that just described; but when the load current becomes zero, the total flux is placed at the value indicated by point *c* during the second control period. This process of positioning the residual magnetic flux is called resetting.

Following the resetting action, the next operating period causes the flux to increase; and a small part of the applied half cycle elapses before saturation is reached with the core at point *a*. At this point, the rectifier is in

maximum conduction and remains so for the rest of the half cycle. When the control period is resumed, the flux returns to point c, being reset to this value by the action of the control circuit. Thus, the primary function of the control current is to determine the starting value of magnetic flux. The output waveform for this amount of control current is shown directly below (B) of figure 5-8.

Part (C) of figure 5-8 shows the result of increasing the amount of control current. Note that conduction in the output circuit occurs only during the latter half of the operating half cycle. The result of a large amount of control current is indicated in (D) of the figure. In this case, the reset point is such that the load flux cannot drive the core to complete saturation; and therefore, the output current is substantially zero, as shown in the corresponding waveform. The method of operation just described is very similar to the action of a thyratron, in which conduction is either maximum or zero, depending on the relationship of the control voltage and the applied plate voltage. The term firing, which is often used in referring to thyratron action, is also frequently used interchangeably with the word saturation when describing the similar condition in magnetic amplifiers.

USING BIAS FOR FLUX RESET.—If the core material has hysteresis characteristics that result in a rectangular-shaped B-H curve, it may be necessary to bias the core to retain control. This is accomplished either by causing a bias current to flow through the control winding or by use of a separate bias coil. With either method, the bias current provides the means for resetting the magnetic flux to the initial operating point during the control period of the amplifier as described in the preceding paragraphs. The use of a separate bias winding for this purpose has the advantage that smaller control current is drawn and loading of the control-voltage source is minimized.

The physical position of the bias winding with respect to the control and load coils in three-legged-core amplifiers is illustrated in figure 5-9. The core is usually biased so that with zero control current, the flux resulting from load current saturates the core material midway in the operating period. In this condition, the bias setting corresponds approximately to operating point c

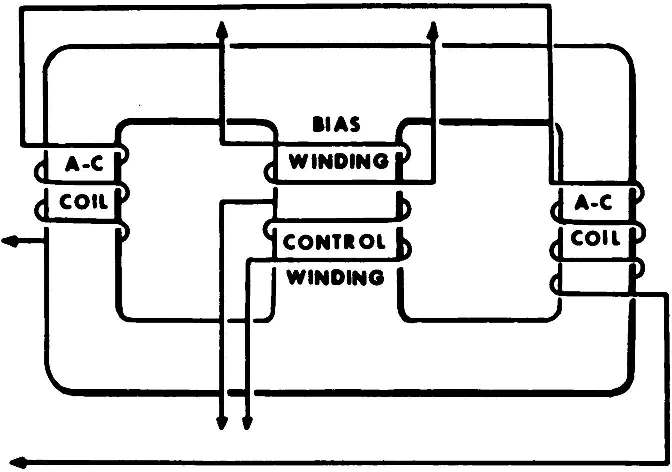


Figure 5-9.—Bias winding.

in figure 5-8 (C), so that the control current can either advance or delay the point of saturation. Thus, if the polarity of the control voltage is such that the control-current flux adds to the bias flux, saturation is delayed and the amplifier fires later in the operating period. A control signal with opposite polarity results in a control flux that opposes the bias flux and hence advances the firing point.

In most cases, the polarity of the d-c bias supply is selected so that the bias magnetism opposes the load-current flux. The magnitude of the bias is usually such that the core flux is reset to a point on the hysteresis curve between points *b* and *c* in figure 5-8 (B). In some applications, the bias polarity is reversed so that it aids the load winding flux and provides quick initial saturation of the core, thereby increasing the amplification of weak input signals. Also, some types of special circuits contain a-c bias systems.

Magnetic Amplifiers with Full-Wave Rectification

In most applications of magnetic amplifiers, full-wave output is desirable rather than the pulsating, or half-wave, operation previously discussed and illustrated. Full-wave

operation in which the load is energized during both halves of the a-c cycle may be obtained by using a pair of half-wave units.

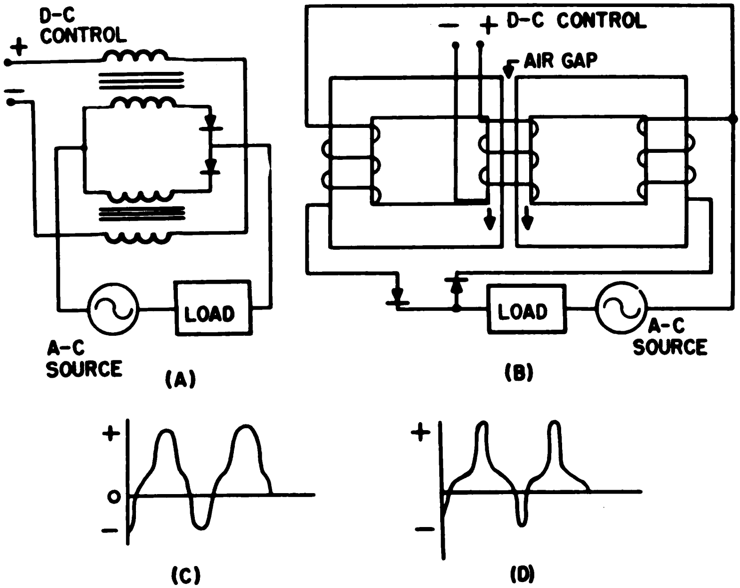


Figure 5-10.—Full-wave magnetic amplifiers and output waveforms.

Typical full-wave circuit arrangements are illustrated in (A) and (B) of figure 5-10. The load current in the amplifier shown in (A) is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately; and as one unit conducts, the core of the other is reset by the action of the control current. With each rectifier conducting approximately one half cycle, the output current variations are full wave in nature.

Output current waveforms are shown in (C) and (D) of figure 5-10; these waveforms indicate the resultants for two different values of control current. Waveform (C) occurs when the control current biases the core near the point of saturation so that heavy conduction begins early in each half cycle of applied voltage. If control current is reduced to a lower value, the output resembles the waveform

in (D), in which the average value of current over each half cycle is considerably less than when the operating point is near saturation. As in the operation of the basic circuit, the output power is varied by controlling the flow of load current; but unlike the halfwave amplifier, current is delivered to the load resistance during both half cycles of applied source voltage.

In operation, the magnetic amplifier shown in (B) of figure 5-10 resembles that illustrated in (A). It differs in circuitry since it contains a single control winding, and also in that two magnetic cores are combined to form what amounts to a three-legged structure. An extremely small air gap separates the two magnetic paths; and the combination may be regarded as two units similar to the circuit illustrated in figure 5-6. The air gap assists in isolating the magnetic flux components resulting from the load coils so that one core remains unsaturated while the other is in saturation. The two load coils conduct alternately but in opposite directions through the load resistor, hence the output current waveforms resemble those shown in (C) and (D).

Crossover Windings

In discussing the theory of operation of the circuits shown in figures 5-6 and 5-10, it was assumed that the rectifiers have zero forward resistance and infinite back resistance. In actual practice this assumption is not valid since rectifiers do not have infinite back resistance. It should be apparent that any back current flowing through the rectifiers shown in figure 5-10 (A) during their nonconducting half cycle will produce a magnetic flux which will tend to drive the core out of saturation. During the conducting half cycle a part of the load current would be absorbed in bringing the core back to the point of saturation, thus reducing the gain of the amplifier.

One method of counteracting this effect is by the addition of a crossover winding to the two magnetic amplifier cores. Figure 5-11 illustrates a magnetic amplifier utilizing full-wave rectification and crossover windings. It should be noted that this circuit is similar to the circuit shown in figure 5-10 (A).

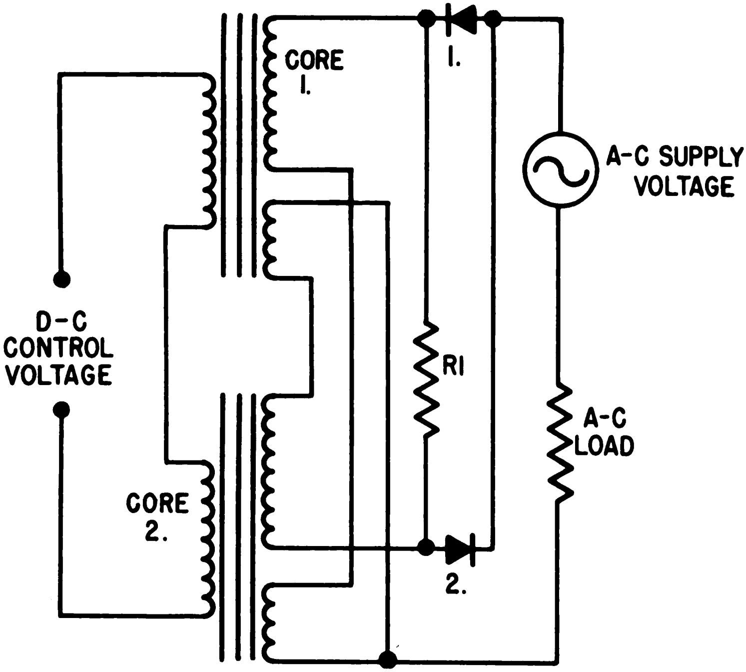


Figure 5-11.—Full-wave magnetic amplifier utilizing crossover windings.

The crossover winding consists of a few turns which produces a magnetic field in a direction opposite to that produced by the backward current through the load winding. Referring to figure 5-11, consider the action of the load and crossover windings on the two cores. Assume that during the first half cycle of the a-c supply voltage, rectifier 1 is conducting in the forward direction. Heavy current flows through rectifier 1 and the load winding on core 1; this current also flows through the crossover winding on core 2. During the same half cycle a small backward current is flowing through rectifier 2, the load winding on core 2, and the crossover winding on core 1. This small backward current flowing through the large number of turns in the load winding produces a magnetic field that is canceled by the heavy current flowing through the small number of turns of the crossover winding on core 2. A similar cancellation is achieved on the second

half cycle of the a-c supply voltage by the other crossover winding.

Since the back resistance of the rectifiers will vary with temperature and applied voltage, some means must be provided to insure cancellation of the field resulting from the backward current at all times. A small constant resistance, $R1$, is connected in parallel to the high, but variable, back resistance of the rectifiers. Each rectifier is shunted during its nonconducting half cycle by the series combination of $R1$ and the conducting rectifier. The variations in the back resistance will now have no noticeable effect on the quantity of backward current through the load windings.

Feedback in Magnetic Amplifiers

It is possible to improve many of the operating characteristics of a magnetic amplifier by the use of an external feedback circuit. In many cases, this circuit consists of an additional coil wound on the center leg of the magnetic core. Feedback action occurs when the coil is energized by a portion of the output current and produces a magnetic field that is combined with the control flux established by the input circuit.

Typical feedback circuits are illustrated in figure 5-12. Each amplifier contains dry-disk rectifiers connected in a bridge circuit. In amplifier (A) the rectifier produces a full-wave d-c output both to the load resistor and to the feedback winding. Amplifier (B) has the load in the a-c circuit and the bridge rectifier provides direct current in the feedback winding only.

Feedback in these amplifiers (fig. 5-12) may be either positive or negative, depending on the connection of the feedback winding. If the flux produced by the latter winding aids the control winding flux, the feedback is positive, or regenerative; if it opposes the control flux, it is negative, or degenerative.

The effect of positive feedback is to make the circuit more sensitive to changes in control current so that extremely high values of gain can be achieved. It has the undesirable effect, however, of increasing the response time of the amplifier, and it may also cause instability. The general effect of negative feedback, on the other hand,

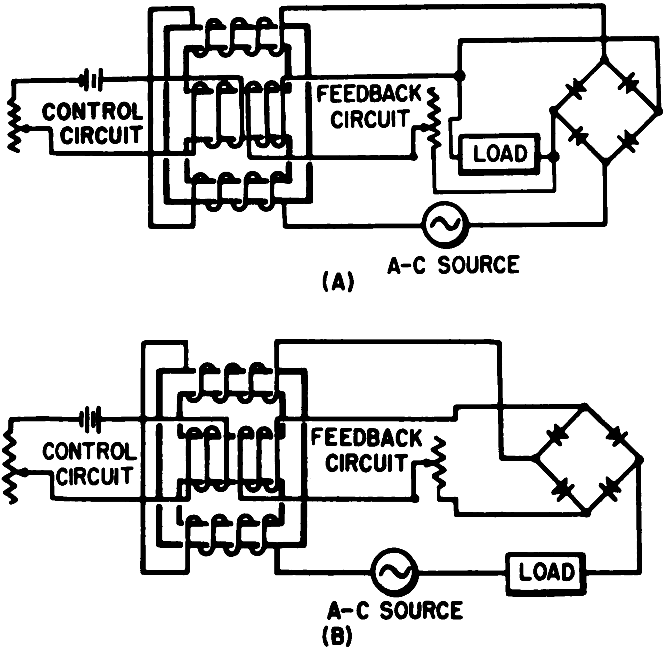


Figure 5-12.—Magnetic amplifiers employing feedback.

is to reduce the sensitivity with a corresponding increase in linearity of the magnetization curve and reduction of the time lag.

Load current is plotted against control current in the curves in figure 5-13 to show the effects of feedback on linearity and on the quantity of control current required. The total control current (input plus feedback currents) needed to saturate the core is the same regardless of the sign or the amplitude of the feedback present.

With positive feedback, less control-circuit current is required because of the additive effect of the feedback and control coils. As indicated in figure 5-13, there is a difference between no-feedback saturation current (B) and the control current present with positive feedback (A). This difference is supplied by the output circuit through the feedback winding. When negative feedback is employed, the current drawn by the control circuit must be increased above the no-feedback value to achieve

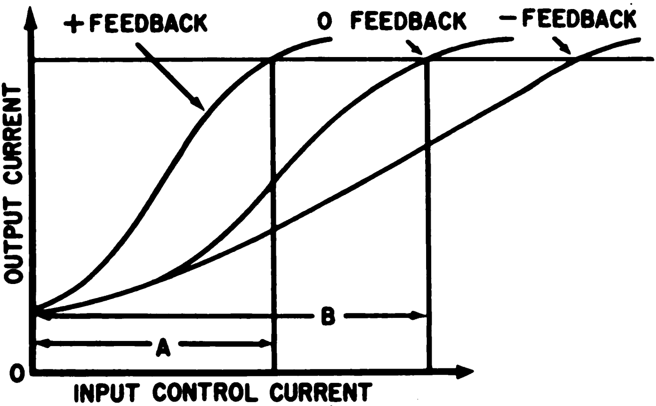


Figure 5-13.—Effects of external feedback.

saturation since the feedback flux is in opposition to the control flux. The effect of negative feedback on linearity of control is indicated by the right-hand curve, which is straight over a much larger range of control current values than the curves for the positive- and no-feedback conditions.

Saturable Reactor Cores

For optimum performance, the laminations of a saturable reactor core should be arranged so that the air gap is as small as possible, and the laminations should be very thin so as to reduce eddy current effects to a minimum. The usual interleaving technique used in conventional transformer core construction is unsatisfactory for saturable reactors in magnetic amplifiers. The many small air gaps provided by butt joints of the standard *E* core distort the magnetization curve, thus making it inadequate for the peak performance necessary in most applications in electrical control equipment. Special design of the *E* core has improved its characteristics by increasing the overlap of the laminations for a greater portion of the magnetic path; however, its performance is somewhat below that desired.

Saturable reactor core material should have low hysteresis and eddy current losses, high saturation flux

density, stable magnetic characteristics, and a hysteresis loop that is rectangular.

The most common core construction used in the better saturable reactors is made by spirally winding a relatively narrow silicon steel tape into a circular (toroidal) or rectangular core as required. A toroidal saturable reactor is shown in figure 5-14. The tape cores are mounted in containers to provide support for the multilayer windings; also, this assures that no mechanical strain will be placed on the cores. Another type saturable reactor core is made by stacking single-piece stamped laminations.

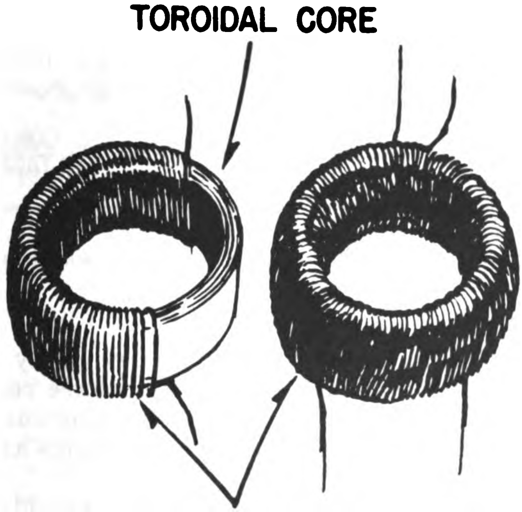


Figure 5-14.—Toroidal saturable reactor.

Since tape wound cores have no center leg, two cores are required in most amplifiers. Figure 5-15 illustrates a basic magnetic amplifier utilizing two cores. The control windings are connected in series-aiding so that a common control current can saturate both cores. The a-c load windings are connected in series-opposing to minimize the alternating current induced in the control circuit.

The physical arrangement of the various toroidal windings (fig. 5-14) on the cores will greatly affect the

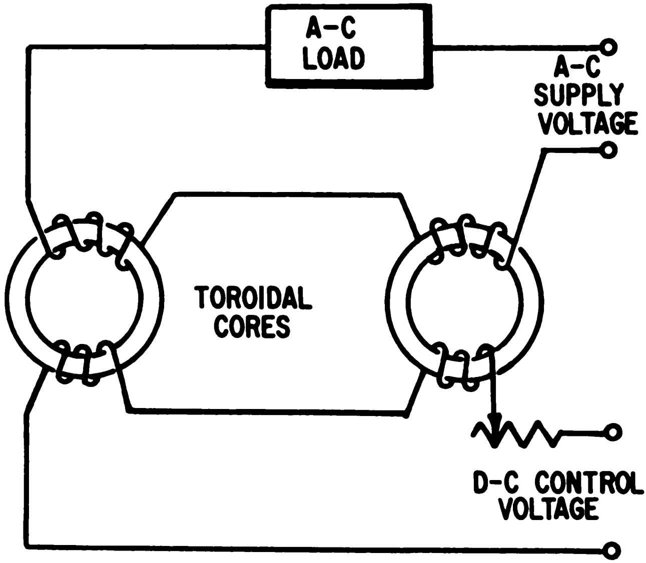


Figure 5-15.—Magnetic amplifier utilizing toroidal windings on tape wound cores.

performance of the magnetic amplifier. They must be wound in such a way that leakage effects are reduced to a minimum and the circulation of alternating currents in the d-c control, bias, and feedback windings are minimized.

Typical magnetic amplifiers utilizing toroidal wound saturable reactors will be discussed under the heading "Magnetic Amplifier Applications." The use of bias, feedback, and crossover windings on these reactors will also be discussed later in the chapter.

Time of Response

Among the basic characteristics of any magnetic amplifier is a lag or time delay between the introduction of a change in input signal and the development of full response by the load circuit. The cause of the time delay lies in the action of the L-R, or inductance-resistance, circuits of the amplifier. Its value is a measure of the sluggishness of operation; and if the response time is long,

the amplifier may be unsuitable for use in equipment such as high speed servo systems.

The time of response of a particular amplifier can be expressed by means of a time constant, which indicates the interval of time in seconds required for the load current to attain a certain percentage of the final value. The greater the time constant, the less rapid the circuit action. Hence, the time-constant value is a leading factor in determining the upper limit of the frequency range of input signals which can be handled by the amplifier with suitable gain.

In magnetic amplifiers of this type, the time constant is determined by the properties of both the control and load circuits. The principal factors are the ratio of the load-circuit and control-circuit resistances, the turns ratio of the control winding to load windings, and the frequency of the power supply in the output circuit. The relationship of these quantities to the time constant is given by the equation:

$$T = \frac{1}{4 f_s} \times \frac{N_c^2}{N_L^2} \times \frac{R_L}{R_c}$$

where T = time in seconds
f_s = source frequency
N_c = number of turns in the control winding
N_L = number of turns in the load windings
R_c = resistance of the input, or control circuit
R_L = resistance of the load circuit

The principal significance of the time constant, T, lies in its relation to the gain of the amplifier with a given input frequency. For adequate amplification, it is necessary that the time constant be short compared with the period of the signal, or the time required for one input cycle. If this is the case, the output current attains the full response for each variation of input voltage. But if T is long relative to the input period, the output variations are low in amplitude because the circuit has insufficient time to reproduce a signal of one polarity before the succeeding change in polarity occurs. Since the period of the input wave varies inversely with frequency, the amplifier should

have a rather low time-constant value if the applied signal frequency is fairly high.

It can be seen from the time-constant equation that with a given load resistance and a fixed turns ratio, the response time of the amplifier can be reduced by increasing either the control-circuit resistance or the a-c power supply frequency. In some amplifiers, resistors are inserted in series with the control winding to increase the total resistance of the input circuit. In others, much the same effect is obtained by use of negative feedback. Both these methods have the disadvantage, however, of lowering the effectiveness of the control winding, since the flux resulting from the input signal is reduced.

The inherent time lag of the magnetic amplifier is reduced more conveniently by use of a high-frequency power source. For high-gain operation, the maximum input frequency is usually limited to a low percentage of the a-c source frequency. For medium- and low-gain performance, the input frequency may range up to a value about 50 percent of the source frequency. The factor limiting the a-c source frequency employed in a particular amplifier is the amount of power loss that can be tolerated due to hysteresis effects in the core material. In some cases, sources in the order of several megacycles have been used.

APPLICATIONS OF MAGNETIC AMPLIFIERS

The magnetic amplifier has found application in many different type circuits. These circuits may employ diodes, vacuum tubes, and transistors. Such circuits may be found in voltage regulators (d-c and a-c), servo amplifiers, and audio amplifiers. The Aviation Electrician will be mainly concerned with their application in servo systems and voltage regulators.

Applications in Servomechanisms

One of the most frequent uses of magnetic amplifiers in electrical equipment is in servomechanism systems. In these applications, the magnetic units have the desirable features of long life, need for minimum servicing, and the

ability to handle large amounts of power for energizing electric motors and other load actuating devices.

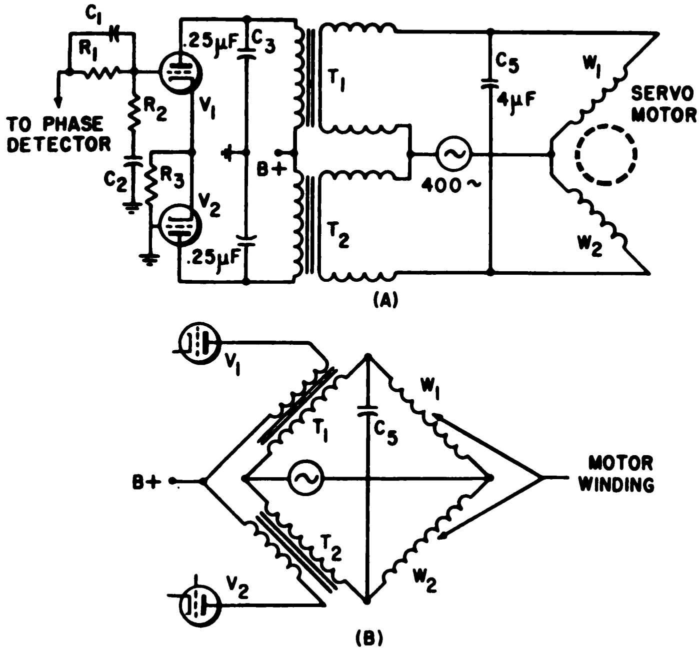


Figure 5-16.—Magnetic amplifier used to control a two-phase induction motor.

MOTOR CONTROLLER.—Figure 5-16 shows a magnetic servo amplifier which controls the voltages for both phases of a two-phase electric motor. The input signals for the magnetic amplifier are produced from a phase detector. These drive *V*1 and *V*2, which are connected as a cathode coupled paraphase amplifier working into two saturable reactors.

With zero input, both tubes (fig. 5-16) draw equal amounts of current in the plate circuits. These currents are insufficient to saturate the cores of the reactors; and therefore, the impedance of each load winding is very high and the resulting load currents are small. In this condition the circuit is a balanced bridge as indicated in

part (B) of figure 5-16; and the motor does not rotate since in-phase voltages are applied to the motor windings.

When an input control signal is supplied from the phase detector, one of the tubes (depending upon the phase and amplitude of the signal) goes into heavier conduction than the other. Under full conduction conditions, the reactor in one plate circuit then appears as a low impedance and the other reactor approaches the open-circuit condition. The bridge is then unbalanced; and capacitor *C*5 is effectively connected in series with one of the motor windings, where it causes a phase shift and the motor begins to rotate.

Assume, for example, that *V*1 (fig. 5-16) goes into heavy conduction and that *V*2 is at effective cutoff. The secondary inductance of *T*1 is then practically zero and motor winding *W*1 is connected across the a-c source. The inductance of secondary *T*2 is high so that the winding resembles an open circuit; and motor winding *W*2 is then connected across the a-c source through the phasing capacitor. The phase relations of the resulting currents cause the motor to rotate in a direction determined by which winding is connected in series with the capacitor. Upon reversal of the control signal, the conditions described also reverse, and *W*1 is placed in series with the capacitor so that the motor then turns in the opposite direction.

Additional servo circuits that utilize magnetic amplifiers are discussed in chapter 7 in connection with servomechanisms.

Power Supply Regulator

The equipment power supplies of aircraft systems must meet certain basic requirements which include ruggedness, long life, and freedom from excessive maintenance problems. To meet these requirements, the development of power supply equipment has resulted, in many cases, in the elimination of the electron tube as the chief cause of failure. The magnetic amplifier has been used to replace the complex arrangements usually necessary for good voltage regulation; and the solid-state power diode is often employed instead of the fragile vacuum tube. An

example of a circuit with these components is shown in figure 5-17.

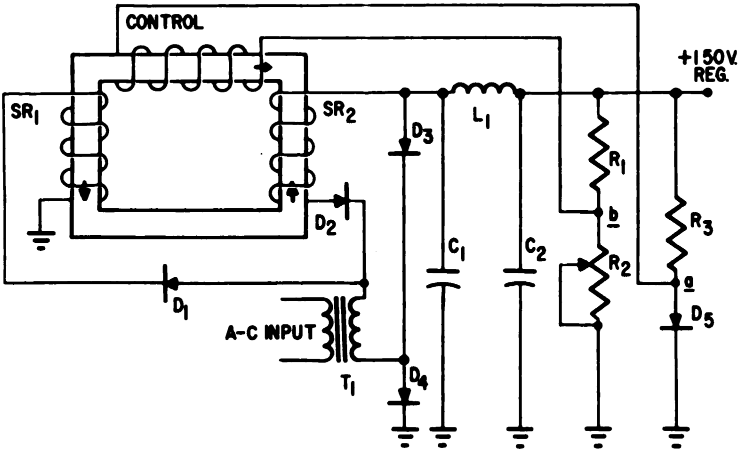


Figure 5-17.—Power supply with magnetic-amplifier regulator.

The circuit is a conventional full-wave bridge rectifier utilizing a magnetic amplifier to control the output and also a Zener diode as a part of the regulating system. The Zener diode element is a solid-state equivalent of the gaseous regulator tube and maintains a constant voltage across the terminals regardless of variations of the current it conducts, within the specified operating range. In the schematic shown (fig. 5-17), the connection of the Zener diode is the reverse of that of an ordinary rectifying diode, since in this example it is the inverse breakdown voltage characteristic which is employed for regulation.

Current flow (fig. 5-17) during one half cycle is through the load, choke *L*1, diode *D*3, the secondary of *T*1, and diode *D*1, then returning to ground through *SR*1 of the reactor. During the other half cycle, the current flows through the load, *L*1, *SR* 2, *D*2, the secondary of *T*1, and *D*4 to ground. In addition to the load current, there is conduction through *D*5 and *R*3 and also through *R* 2 and *R*1.

The control winding of the magnetic amplifier is energized by the voltage between the junction of *R*1 and *R* 2 and the upper terminal of the Zener diode, *D*5. When the output voltage is of the proper value, the potential across

the control winding (and therefore the current through it) sets the magnetic bias of the reactors at the operating point, which is well up on the magnetization curve to obtain a high percentage of the source voltage.

If the output voltage tends to rise, the voltage at point *a* remains constant due to the action of the Zener diode; but the voltage at point *b* increases. This causes a change in the current flowing in the control winding so that the bias point is shifted to a value that results in lower conduction in the load coils. As a result, the voltages across *SR*1 and *SR*2 are increased and the output voltage decreases.

When the output voltage tends to decrease, the potential at point *b* falls with respect to that at point *a* and the control current changes the bias to a point of higher conduction. This lowers the voltage drops across the a-c coils of the reactors and increases the value of the output. Capacitors *C*1 and *C*2, together with *L*1, are connected to form a pi-section filter which smooths the output to give a nearly pure d-c voltage. Resistor *R*2 is adjustable, being set to the value for optimum operating voltage in normal use. It also provides a means for making adjustments to compensate for any changes that occur in the circuit components.

A gas-filled regulator tube (VR-75) could be used in of the Zener diode. The voltage regulation and operation would be the same.

A more complex voltage regulator that utilizes magnetic amplifiers is discussed in chapter 6, under the heading "A-C Generator Voltage Regulators."

Advantages and Disadvantages

The principal advantages of the magnetic amplifier in the electrical and electronic fields are ruggedness and long life, and the resulting decrease in component failures. Magnetic circuits do much to lessen the maintenance and repair load by elimination of fragile filaments; while at the same time, they have the desirable feature of almost zero warmup time.

The reduction in heat, resulting from the elimination of filaments and the plate dissipation common to vacuum tubes, lessens the need for blowers and other cooling

equipment. In most cases, high-voltage d-c power supplies are not required, which is an important safety consideration. Typical amplifiers are capable of high individual stage gains of voltage or power; impedance matching can be effected easily; and the magnetic units are usually constructed so that they can be isolated from other parts of the equipment such as output circuits.

On the other hand, the bulkiness of magnetic equipment is frequently a deterrent to its use, since most reactors designed for operation on 60 cycles are much heavier and larger than their electronic counterparts. The trend toward use of 400- and 800-cycle power frequencies, however, has helped materially in reducing the size and weight of the magnetic units.

Among the disadvantages of magnetic amplifiers is the inherent time lag typical of most reactors; and this characteristic alone often restricts their usefulness. In addition, distortion is a limiting factor, not only because of the inability of the amplifier to reproduce the input waveforms with precision, but also because of the harmonic frequencies generated by distortion. These often make it necessary to employ shielding so that nearby equipment is not subjected to undesirable radiation.

While magnetic amplifiers operate efficiently within a fairly wide range of temperatures—about -60° to 212° F. —they have limitations with regard to temperature. Deviation from the normal range, either above or below, may alter the magnetic properties of the core materials and materially change the operating characteristics of the amplifier. When dry-disk rectifiers are used as associated circuits elements, as is the case in many units, their operation may likewise be affected by temperature extremes.

Although magnetic amplifiers often serve to replace vacuum tubes, they are not as versatile; and in numerous cases, the magnetic unit is used in conjunction with the electronic amplifier to utilize the major advantages of each. Usually, vacuum tubes are more suitable in the earlier stages of signal sequence, deriving the required voltage gains with minimum distortion; while magnetic amplifiers are used principally in the last stages to develop high power outputs at comparatively low d-c voltage levels.

In general, the advantages of the magnetic amplifier outweigh the disadvantages. You can expect to find them installed in more and more of the equipment that you are required to maintain.

QUIZ

1. In the formula for self inductance

$$L = \frac{1.256\ N^2 A \mu 10^{-8}}{l},$$

   the L
   a. varies inversely as the square of the number of turns
   b. varies inversely as the length is increased
   c. varies inversely as the area is increased
   d. is not affected by changes in permeability

2. The outstanding limitation of a magnetic amplifier as compared to a vacuum-tube amplifier is
   a. that it will not effectively amplify weak d-c signals
   b. the difficulty encountered in matching the amplifier to the input signal
   c. the instability, due to its varying magnetic properties caused by changing temperature and shock conditions
   d. the sluggish response

3. In figure 5-1, when the core is completely within the winding, the load current
   a. is maximum
   b. is minimum
   c. remains unchanged
   d. is greatly increased

4. As complete saturation of a magnetic material is approached, the permeability
   a. changes very little throughout the magnetizing process
   b. is practically the same as at the saturation point
   c. increases rapidly
   d. is nearly one

5. The value on the hysteresis loop that indicates the amount of flux remaining in the material after the magnetizing force has been removed is called the
   a. saturation point
   b. curie point
   c. remanence point
   d. firing point

6. A magnetic amplifier used to control a two-phase induction motor such as shown in figure 5-16 is a/an
   a. balanced bridge circuit with maximum input
   b. unbalanced bridge circuit with zero input
   c. balanced bridge circuit in which the motor does not rotate when the input signal is zero
   d. balanced bridge circuit with zero input and the motor does not rotate since out-of-phase voltages are applied to the motor windings

7. By using feedback circuits in magnetic amplifiers, it is possible to
   a. maintain a more linear performance curve through the use of positive feedback
   b. increase power amplification through the use of negative feedback
   c. provide greater stability through the use of positive feedback
   d. obtain faster response time through the use of negative feedback

8. In the power supply regulator circuit such as shown in figure 5-17, the purpose of the Zener diode (*D*5) is to
   a. increase the voltage across the terminals when it does not conduct
   b. maintain a constant voltage across the terminals regardless of the current variations while conducting
   c. decrease the voltage across the terminals when it conducts
   d. maintain a constant current regardless of voltage changes

9. The time of response of a magnetic amplifier may be increased
   a. by decreasing the resistance in series with the control coil
   b. by adding turns on the control coil
   c. through the use of a positive feedback winding
   d. by adding a capacitor in parallel with the control winding

10. In a magnetic amplifier with a half-wave rectifier, the interval during which the rectifier conducts is called the
   a. operating period
   b. control period
   c. resetting period
   d. saturating period

11. Bias coils and feedback coils are used in magnetic amplifiers to permit (1) wide control of gain and (2) speed of response, because
   a. regenerative feedback gives greater power amplification and a shorter time of response
   b. degenerative feedback gives less power amplification and a longer time of response
   c. bias coils, by providing an initial saturation of the core, may increase the power amplification and will reduce the time of response
   d. regenerative feedback tends to provide greater stability than degenerative feedback

12. In the time constant equation,

$$T = \frac{1}{4f_s} \times \frac{N_C^2}{N_L^2} \times \frac{R_L}{R_C}$$

the T varies
   a. directly as the square of the number of turns in the load windings
   b. directly as the source frequency
   c. inversely as the resistance of the control circuit
   d. inversely as the square of the number of turns in the control winding

13. In the basic magnetic amplifier (fig. 5-3), control action is accomplished by
   a. varying the load current
   b. changing the permeability of the core
   c. varying the load voltage
   d. changing the resistance of the load

14. Since rectifiers do not have infinite back resistance and during their nonconducting half cycle will produce a flux which will tend to drive the core out of saturation, magnetic amplifiers were developed utilizing
   a. bias windings
   b. feedback windings
   c. crossover windings
   d. control windings

15. The chief advantage of positive feedback in magnetic amplifiers is
    a. that it decreases the effective resistance of the control coil
    b. an increased time of response
    c. the increased power amplification
    d. more linear response with shorter response time
16. In magnetic amplifiers utilizing toroidal windings on tape wound cores the
    a. control windings are connected in series-opposing so that a common control current can saturate both cores
    b. control windings are connected in series-aiding so that a common control current can saturate both cores
    c. a-c load windings are connected in series-aiding to minimize the alternating current induced in the control circuit
    d. control windings are connected in series-opposing to minimize the alternating current induced in the load circuit
17. In a simple magnetic amplifier, the control winding is connected to a
    a. fixed a-c source
    b. variable d-c source
    c. fixed d-c source
    d. variable a-c source
18. In the three-legged saturable reactor the two a-c coils
    a. have the same number of turns
    b. have a different number of turns
    c. have different inductive reactance
    d. are connected series-opposing
19. The most outstanding advantage of a magnetic amplifier as compared to a vacuum-tube amplifier is the
    a. ruggedness and short life
    b. decreased maintenance and higher frequency response
    c. feature of almost zero warmup time
    d. lower initial cost
20. The chief advantage of degenerative feedback in magnetic amplifiers is
    a. the increased power amplification
    b. the more linear response with shorter response time
    c. an increased time of response
    d. that it decreases the effective resistance of the control coil

21. The lag in the induction of a coil with respect to the magnetizing force, is called
    a. reluctance
    b. hysteresis
    c. inductive reactance
    d. impedance
22. Bias coils are used in magnetic amplifiers primarily to
    a. fix the d-c flux density at a predetermined operating level
    b. increase the reactance of the a-c coils when d-c signal current is zero
    c. increase load current when the core is saturated by the d-c signal current
    d. provide more linear response of the a-c circuit under varying d-c control
23. In any magnetic circuit the flux varies
    a. inversely as the permeability of the core
    b. inversely as the magnetomotive force
    c. inversely as the reluctance
    d. directly as the length
24. The response time of a magnetic amplifier
    a. may be increased by using positive or regenerative feedback
    b. is not affected by the d-c control coil, since d-c flows readily in an inductance coil
    c. is shorter when designed for high-frequency systems, than low-frequency systems
    d. may be decreased by decreasing the resistance of the control coil circuit
25. One of the oldest forms of magnetic amplifiers is the
    a. flux gate compass
    b. saturable transformer
    c. saturable reactor
    d. transformer

CHAPTER 6

ALTERNATING-CURRENT MACHINERY

ROTATING-FIELD A-C GENERATORS

Practically all a-c generators currently used in naval aircraft are of the rotating-field stationary-armature type. Generators of this design offer a number of distinct advantages.

Those windings from which generated power is taken are designated as armature windings. If the armature were a rotary member, relatively heavy sliprings would be required to conduct generated power between the armature and external load. These sliprings, with their high voltage, would necessarily be exposed, and thus difficult to insulate. In addition, they would be a constant source of trouble due to arcing and brush wear, and this trouble would be aggravated by heavy loads. These rings would not be required if the armature were a stationary member. The conductors of a stationary armature could be insulated continuously between the generating coils and the load with no exposed copper. If the rotor is used as the field, sliprings are still required, but they are much smaller and give less trouble. This is because field power is small when compared to the power in the armature.

As the slots are deepened in a generator rotor, they must become narrower. However, as the slots are deepened in the stator, they become wider. For this reason,

more copper may be wound in the stator than in the rotor, because of the stator's greater slot volume. This increased copper volume increases the capacity of the generator, and provides more room for insulation between the armature conductors. Since the power for the field excitation is very small when compared to the power in the output armature, it is quite logical that the rotor, with its limited copper volume, should be used as the field.

Generator Windings

The fundamental principles which apply to a-c generator windings are the same as those applying to d-c generators. That is, the span of any generating coil must be equal, or nearly so, to the pitch between adjacent field poles. The terms COIL SPAN and POLE PITCH are explained in figure 6-1. It can also be seen in figure 6-1 that when coil span and pole pitch are equal, the two sides of a coil are centered over field poles of opposite polarity. Thus, the coil sides induced voltages are additive around the coil loop.

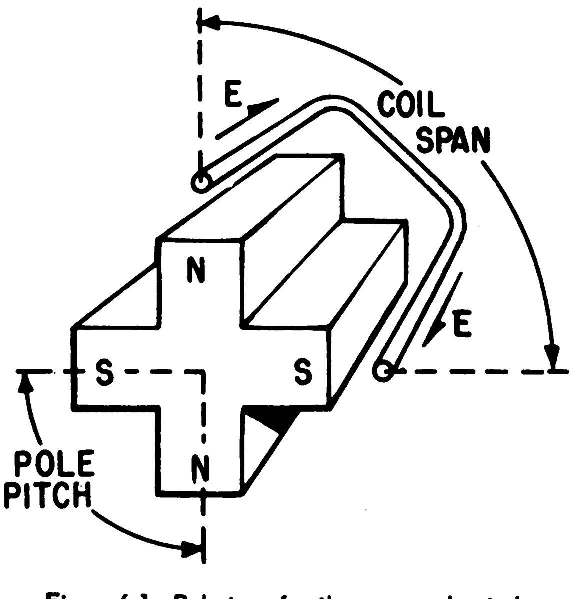


Figure 6-1.—Relation of coil span to pole pitch.

In addition to consideration given the span and placement of the coils, all the coils making up a generating phase must be connected in such a way that coil loop e.m.f.'s are also additive. Further, it is important that the coils be designed so that the wave of generated voltage is as nearly sinusoidal as possible.

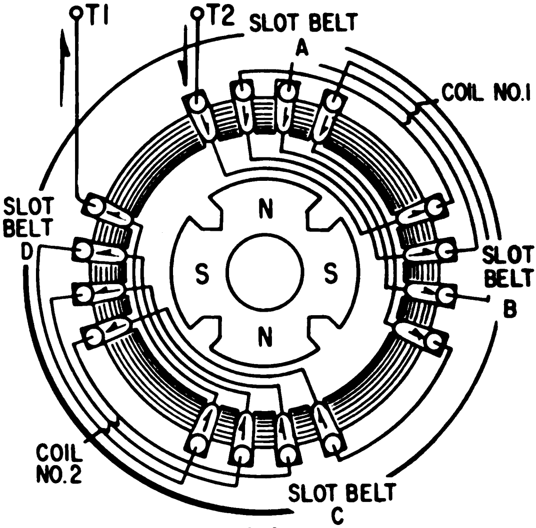
SINGLE-PHASE WINDINGS.—These windings are not used in modern aircraft a-c generators. A single-phase machine has only about 60 percent of the power rating of a three-phase machine of equal weight. For this reason, generators are constructed and wound three-phase. However, loads requiring single-phase power may be connected line-to-neutral on a three-phase generator.

The single-phase winding will be explained merely as an aid in understanding the three-phase winding. This is possible because a three-phase winding may be treated simply as three single-phase windings placed symmetrically around the armature frame. Therefore, an understanding of a single-phase winding will be of considerable help in understanding the three-phase winding.

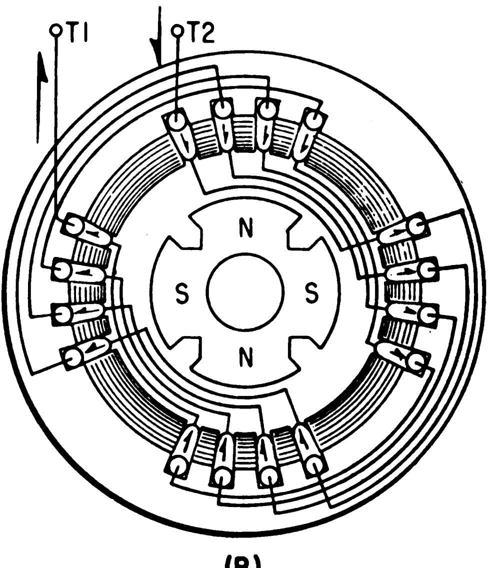
Figure 6-2 represents a simple half-coil, single-layer, single-phase a-c generator. Each coil side consists of a belt of four conductors. There are two coils, though they bear little resemblance to a coil as it is usually visualized. Since there are four field poles, there are half as many complete armature coils as field poles, hence, the term half-coil is derived.

The term single-layer is derived from the fact that there is only a single conductor or conductor group, per slot. Coil 1 occupies slot belts A and B, while coil 2 occupies slot belts C and D. Keeping in mind the requirement that the two sides of a coil must lie under field poles of opposite polarity, it can be seen that two additional coils could be added to the generator. The additional coils may be placed to span slot belts B and C, and belts A and D. The generator would then be whole-coil two-layer. That is, there would be as many armature coils as field poles, and two conductors in each slot. The whole-coil two-layer type of construction is used extensively in aircraft a-c generators.

In a three-phase generator, there are as many coils in each phase as there are field poles. When the generator in figure 6-2 is improved by deepening its slots



(A)



(B)

Figure 6-2.—(A) Simple lap-wound generator; (B) simple wave-wound generator.

and adding additional coils, it appears as shown in figure 6-3. The drawing is simplified to avoid confusion. Note how the coils must overlap.

Since the number of generating conductors is doubled, the output e.m.f. of the generator is also approximately doubled, assuming coils 3 and 4 were connected in series with coils 1 and 2 which were already on the generator. Had coils 3 and 4 been connected in parallel to coils 1 and 2, the output e.m.f. would have remained the same and the current capacity would have been doubled. In either case, the efficiency of the generator has been improved by more efficient utilization of the available generating copper space in the armature.

In the simple machines shown in figures 6-2 and 6-3, however, there still remains wasted space between conductor belts. In practical machines, you will never

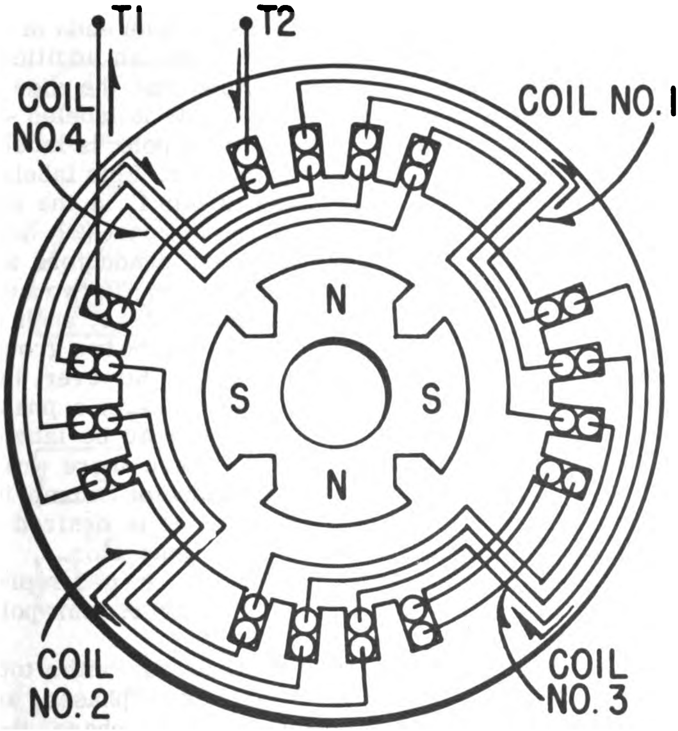


Figure 6-3.—Single-phase whole-coil two-layer generator.

encounter such a feature. Instead, the entire face of the armature will be utilized. There will be a continuous series of slots around the armature face, and each slot will be as deep as is practical. The efficiency of those machines shown in figures 6-2 and 6-3 could thus still be further improved by slotting the wasted armature space, and adding still more coils, thus forming additional phases. Before entering into a discussion of the more complex machines, however, it is necessary to present a simple method of depicting their winding layout. This method is explained in figure 6-4.

Part (A) is a simple machine whose windings are illustrated in the same manner used thus far. If the generator were broken at the fracture lines shown in (A), and then unrolled, it would appear as shown in (B). Note that only the shape is changed. That is, conductor groups still lie beneath the same poles, direction of induced e.m.f. is the same, and connections at both ends of the conductors are still shown. Also in (B), an additional illustrative feature is introduced. Note that the side of coil A that lies beneath a south field pole is labeled +A, and its other side, beneath a north field pole, is labeled -A. Coil B is labeled in a similar manner. This labeling pertains to the direction of induced e.m.f. in the coil sides. It serves an additional purpose in part (C), however. In (C) the connections between conductors are visible only at one end of the conductors. If two conductor groups bear the same labeling letters, such as +A and -A, then the viewer can assume that the two groups are interconnected at their hidden ends. However, in a three-phase generator, all the conductors in a phase, comprising more than just two groups, may be labeled with the same letter. In this way, where there are a great number of conductors, those conductors comprising one phase may be picked out when it is desired to analyze the winding pattern for a given generator.

THREE-PHASE GENERATORS.—Figure 6-5 represents a three-phase, half-coil, single-layer, four-pole, a-c generator.

The armature face is slotted continuously, with a total of thirty-six slots. Since there are three phases, and one-third of the slots are allotted to each phase, then there are twelve slots for each phase. Being a four-pole

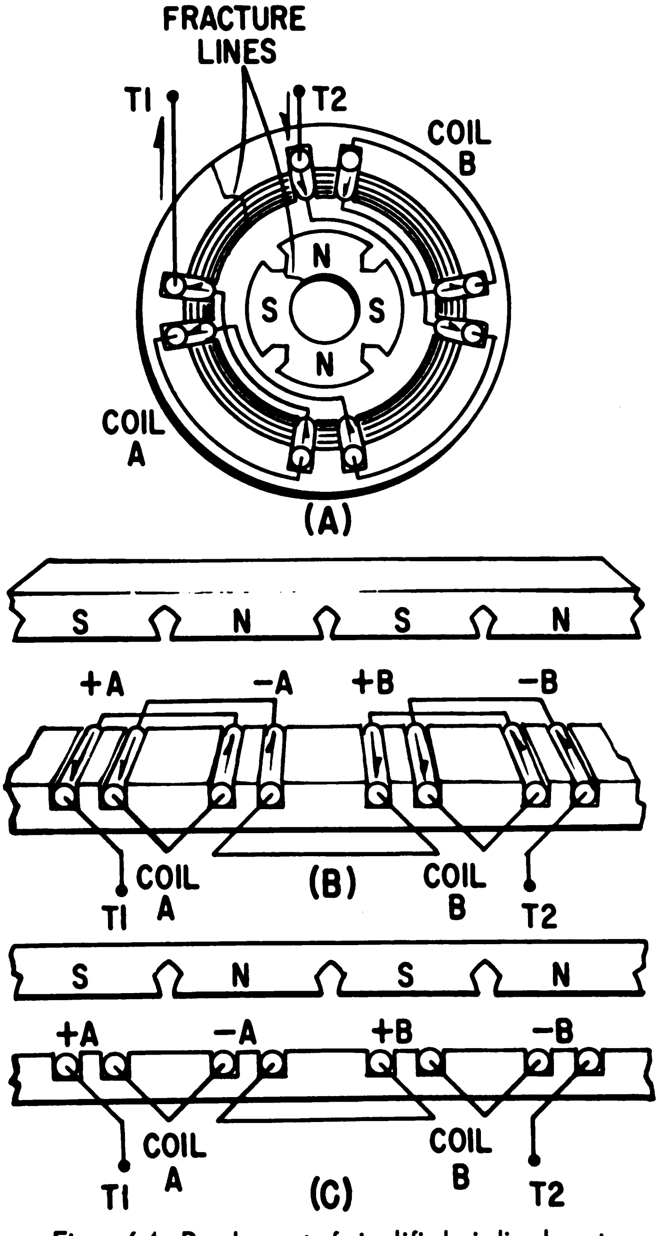


Figure 6-4.—Development of simplified winding layout.

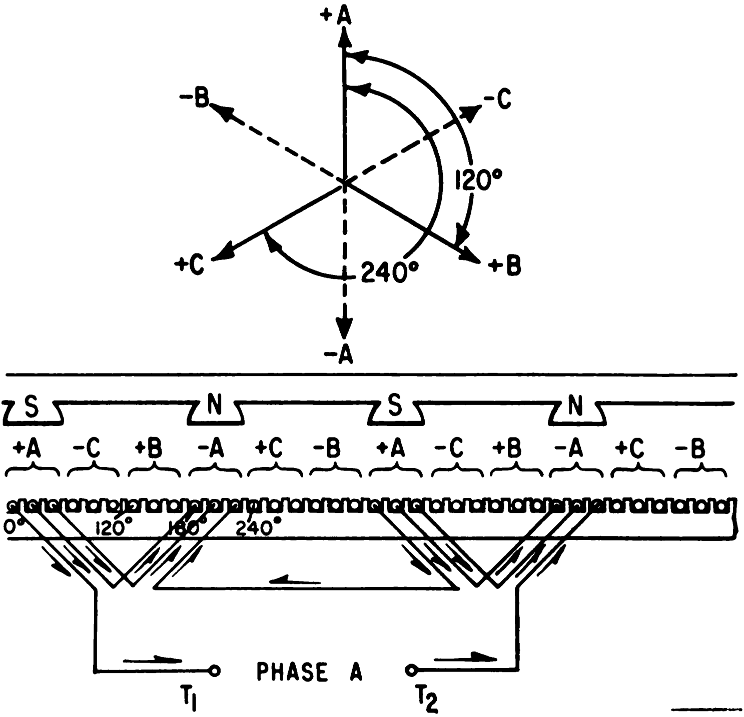


Figure 6-5.—Three-phase, half-coil, single-layer, four-pole, a-c generator.

machine, the generator thus has three slots per pole per phase. That is, each phase is distributed in belts around the armature in such a way that an equal number of conductors, or slots, of that phase lie beneath each field pole. Note that all belts of a phase lie directly under their respective field poles at a given time. In figure 6-5, all belts of phase A are in this position, so that at the instant shown, the e.m.f. of phase A is maximum. All twelve conductors are connected additively so that their e.m.f.'s combine, as shown by the arrows. Their combined value appears across the terminals *T*1 and *T*2. For simplicity, the end connections for phase B and C are not shown. (If shown, they would appear exactly as those for phase A.)

Successive belts are 180 electrical degrees apart, since they lie beneath opposite field poles. The first conductor in a +A belt is 180° ahead of the first conductor

in a -A belt. They are ten slots apart. If slot 1 is considered as 0°, and slot 10 is 180°, then there are 9 slots, or steps, between them. Therefore, the electrical pitch for each slot is 20° (180°/9 = 20°).

If the phase rotation of a generator is ABC, this means that the phases of that generator must pass their positive peaks in that sequence, 120° apart. The rotation for the generator in figure 6-5 is ABC. Starting with phase A at peak positive, as shown, then phase B should be 120 electrical degrees away. That is, starting with the first conductor in a +A belt at a given place, then the first conductor in a +B belt should lie in a slot 120 electrical degrees away. This condition exists in figure 6-5. Slot 1 contains the first conductor of a +A belt, and slot 7 contains the first conductor of a +B belt. Starting at slot 1, there are six steps to slot 7. Since each slot, or step is 20°, then the two conductors are 120° apart (20° × 6 = 120°). Since the positive peak voltage in phase C must occur 240° after the peak in phase A, then the first conductor in a +C belt should lie 240° away from the first conductor in a +A belt. This condition also exists in figure 6-5. The first conductor in a +C belt lies in slot 13, or 12 steps past slot 1. It is, therefore, in its proper electrical position of 240° (20° × 12 = 240°).

After locating the plus sides of the coils, it is a simple matter to locate the minus sides, because the two sides of any coil must lie 180° apart, in a full-pitch winding. (The difference between full-pitch and fractional-pitch winding is discussed later.) It will also help if the ordinary three-phase vector is kept in mind. Referring once more to figure 6-5, note that the vectors are in the same sequence as the generator windings. Starting with +A and progressing around the vectors in a clockwise direction, the vectors are encountered in the same sequence as starting at the first +A conductor belt in the generator and progressing to the right.

Figure 6-6 represents a more practical generator that may be developed from the one in figure 6-5. There are still thirty-six slots, and three slots per pole per phase. However, the slots have been deepened and two more coils added. The generator has thus become a whole-coil, two-layer machine. By starting at *T*2 in figure 6-6, and tracing the path of e.m.f. indicated by the arrows, the

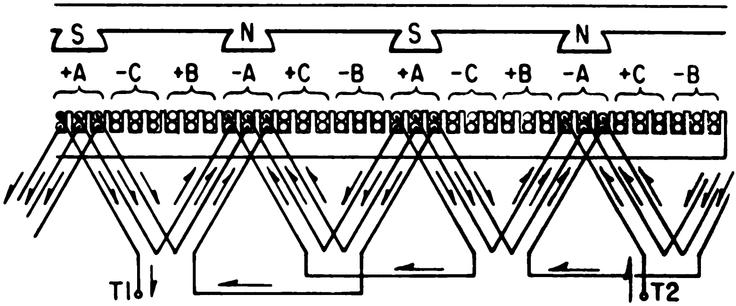


Figure 6-6.—Three-phase, whole-coil, two-layer, four-pole, a-c generator.

entire phase, including all twenty-four slot conductors, will have been traversed by the time *T*1 is reached. Despite its rather complex appearance, the entire phase A is a single series path between *T*1 and *T*2. If the end connections for phases C and B were shown, there would be only three complete traceable paths through the generator; one for each phase.

In practice, small a-c generators will generally have a single series path through each phase. However, large machines will generally have a combination of parallel paths comprising each phase. In this way, individual coil conductors are not required to be of sufficient size to carry the full line current, as they would in a series connected arrangement. The phase terminal voltage is the same as any parallel coil voltage, but each coil current is only a fraction of the total phase current.

In some a-c generators, the armature coils do not span a full 180 electrical degrees. That is, when one coil side is directly under a field pole, the other side does not lie fully centered under an opposite pole. This is known as a fractional-pitch winding. A generator wound in this manner is shown in figure 6-7.

The fractional-pitch winding type generator is similar in all respects to the one shown in figure 6-6 except that the entire bottom layer of conductors has been slipped back one slot. As previously determined, the electrical pitch between slots is 20°, so that the span of any coil is now 160°. (180° - 20° = 160°). The coil sides obviously no longer reach their respective peak and zero positions

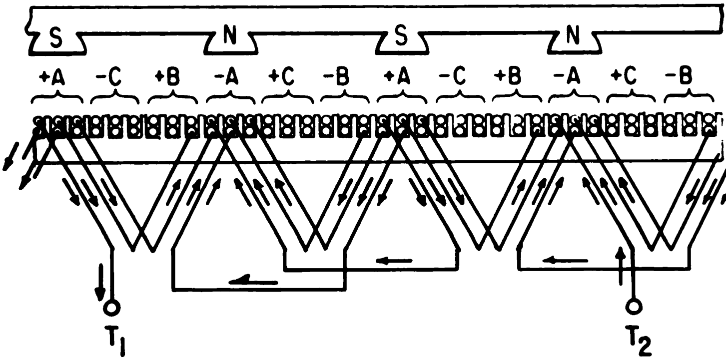


Figure 6-7.—Three-phase fractional-pitch generator.

simultaneously. As a result, the effective output of the generator is somewhat reduced.

In determining the voltage generated in a fractional-pitch coil, the pitch factor must be considered. For an explanation of the pitch factor, refer to figure 6-8.

Part (A) represents the e.m.f.'s in a full-pitch coil. The total coil e.m.f. (E_c) is obviously twice either coil side e.m.f., or E_c = 2eA or 2eB. In part (B), however the coil side e.m.f.'s are not a full 180° apart. If (B) represents the e.m.f. of any coil in the generator shown in figure 6-7, where the coil pitch is only 160°, then E_c must be somewhat less than in (A) because eB has not reached its peak at the instant shown. It lacks 20°. Consequently, E_c in (B) is

$$E_c = 2eA \times \text{Cos } \frac{20^\circ}{2}$$

$$= 2eA \times \text{Cos } 10^\circ$$

$$= 2eA \times 0.984.$$

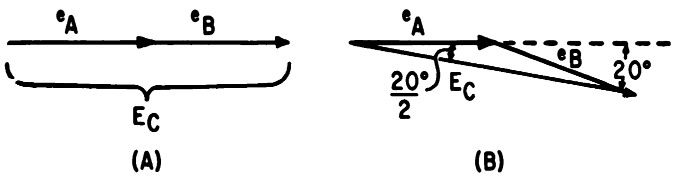


Figure 6-8.—(A) Full-pitch coil e.m.f.; (B) fractional-pitch coil e.m.f.

The pitch factor for the generator in figure 6-7 is thus shown to be 0.984.

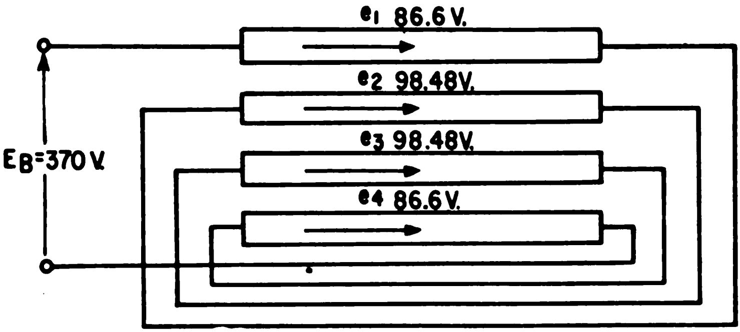
The loss of generated voltage is more than compensated for by at least four additional effects of the fractional-pitch winding. First, the coils are narrower and less copper is required in the end connections. Second, there is less inductance in a coil, because certain of its conductors occupy slots which also contain conductors of other phases. Third, the waveform of generated voltage is improved, and, fourth, harmonics are greatly reduced. In fact, the ninth harmonic for the generator in figure 6-7 is eliminated entirely, because its fraction of winding is eight-ninths ($160°/180° = 8/9$). In a 5/6 pitch winding, the sixth harmonic is eliminated, in a 4/5 pitch winding the fifth, and so on.

An additional factor that affects generated e.m.f. must be considered when phase belt conductors are distributed in a number of slots. Figure 6-9 represents a four-conductor belt which is exactly centered under its field pole. If the four conductors are connected in series additive, the belt e.m.f. must obviously be at maximum at the instant shown. Assuming each conductor generates a peak of 100 volts, then the belt e.m.f. would be 400 volts if all conductors reached their peaks simultaneously. Of course, they cannot do this because they are spaced 20 electrical degrees from each other. Total belt e.m.f. is the sum of the four-conductor e.m.f.'s, and each conductor e.m.f. may be computed if it is known how many electrical degrees each conductor lies away from its peak. In figure 6-9, the e.m.f. of conductor 1 or 4 is

$$\begin{aligned} e_1 \text{ or } e_4 &= 100 \times \text{Sin } (90° - 30°) \\ &= 100 \times \text{Sin } 60° \\ &= 100 \times 0.866 \\ &= 86.6 \text{ volts.} \end{aligned}$$

The e.m.f. of conductor 2 or 3 is

$$\begin{aligned} e_2 \text{ or } e_3 &= 100 \times \text{Sin } (90° - 10°) \\ &= 100 \times \text{Sin } 80° \\ &= 100 \times 0.9848 \\ &= 98.48 \text{ volts.} \end{aligned}$$



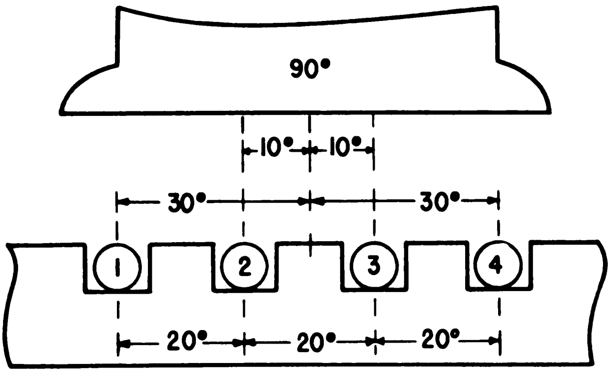


Figure 6-9.—Belt factor of distributed winding.

The total peak belt e.m.f. is

$$E_B = e_1 + e_2 + e_3 + e_4$$

$$= 86.6 + 98.48 + 98.48 + 86.6$$

$$= 370 \text{ volts (approx.)}.$$

It can be seen that the e.m.f. is reduced from 400 volts, where the conductors are concentrated, to 370 volts, where they are distributed. This effect is referred to as the breadth or belt factor, and is symbolized by K_B. It must be included when computing generated voltage. The belt factor for the phase belt shown in figure 6-9 is

$$K_B = \frac{370}{400} = 0.925.$$

For further clarification, total phase e.m.f. will be computed for the generator shown in figure 6-7, which will involve both the pitch factor K_P and belt factor K_B. The pitch factor has already been determined as 0.984. Assuming peak conductor e.m.f. is 10 volts, the belt factor for the three-conductor groups is determined as follows: The center conductor is at a peak of 10 volts. The remaining two conductors are each 20° away from peak, so their instantaneous e.m.f. is

$$\begin{aligned} e &= 10 \times \text{Sin}\ (90° - 20°) \\ &= 10 \times \text{Sin}\ 70° \\ &= 10 \times 0.9397 \\ &= 9.4 \text{ volts (approx.).} \end{aligned}$$

The belt factor is

$$\begin{aligned} K_B &= \frac{9.4 + 10 + 9.4}{10 + 10 + 10} \\ &= \frac{28.8}{30} \\ &= 0.96. \end{aligned}$$

Since there are a total of twenty-four series-connected conductors, total phase e.m.f. across $T1$ and $T2$ is

$$\begin{aligned} E_T &= 10 \times 24 \times K_P \times K_B \\ &= 10 \times 24 \times 0.984 \times 0.96 \\ &= 226 \text{ volts (approx.).} \end{aligned}$$

Generator Construction

ARMATURES.—When in operation, the iron in the armature is continuously cut by field flux of alternating direction. As a result, eddy currents are induced in the

iron, causing heat and flux pattern distortion. To minimize eddy currents, the armature is built up of a great number of thin layers, each partially insulated from the other. By confining the eddy currents in this manner, their total detrimental effects are greatly reduced. This method of construction is referred to as lamination. To construct a generator in this manner, circular or semicircular pieces with the same form as a cross section of the finished armature are punched out of thin sheets of iron. The armature is then constructed by stacking the punchings and bolting them together. The armature iron is further supported by an outer steel frame of generally cylindrical shape, or bound together by steel clamping bands. In some cases, the laminations are sandwiched between heavy steel end plates.

If required by design specifications, the armature may have ventilating ducts running through the iron for cooling purposes. As a rule, small generators are cooled sufficiently by air passage through the winding and slot spacing, and do not require ducting. Aircraft generators invariably have cooling air impellers as an integral part of the rotor or will employ blast tubes which force cooling air through the generator. It is important that the heat distribution be uniform throughout the armature, to avoid hot-spots which would limit the rating of the machine. The rating of a machine is linked directly to the internal temperatures it can withstand.

SLOTS.—Armature slots may be either of two types—open, or semiclosed. The open type, shown in figure 6-10 (A), lends itself readily to ease of manufacture, since coils may be inserted in the slots as a package, often being wound, formed, and insulated separately. However, generators of open-slot construction have certain undesirable characteristics, such as flux tufting and distortion, which makes them unsuitable for widespread use in aircraft. Use of the semiclosed type as shown in figure 6-10 (B) is nearly universal in naval aircraft. With this type of slot there is less distortion of the air-gap flux between field and armature, and consequently less rippling and distortion of the generated wave.

In both types of slots, the windings must be held securely in place because of vibration and electromagnetic stress. This is usually done by the use of wedges.

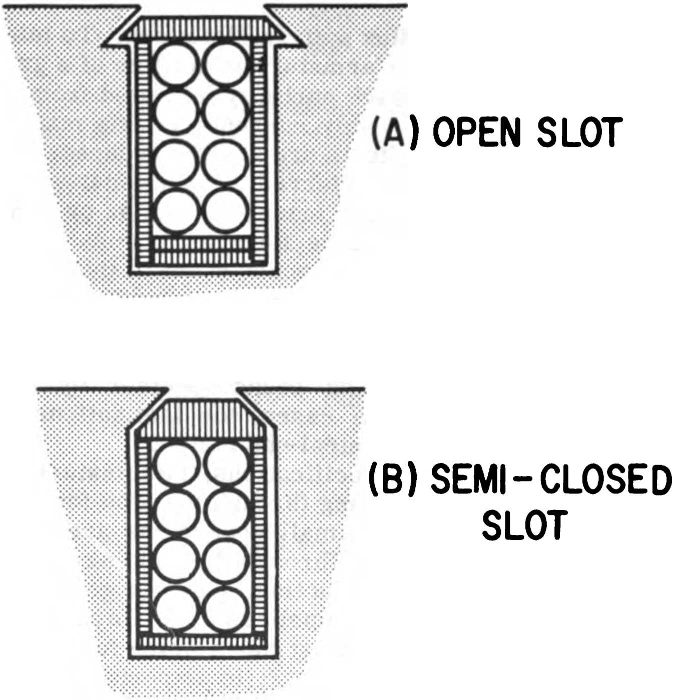


Figure 6-10.—(A) Open slot; (B) semiclosed slot.

Coil insulation falls into two general categories—organic base, or mineral base. The organic types are identified as class A, and include such materials as cambric and paper. When impregnated by varnish, class A insulation is limited to an operating temperature of about 100°C. Class B, or mineral insulation, includes materials such as asbestos, mica, and fiberglass. When these materials are impregnated with silicone base varnishes their operating temperature is about 160° C.

In practice, generating coils are not single solid conductors, as shown in the illustrations up to this point. Solid conductors were used only for ease of explanation. Instead, the slot conductors are stranded. The parts, or strands, of a conductor nearer the top of a slot have less self-inductance than those at the bottom. This is true because the strands at the bottom are effectively

more completely surrounded by iron, and have more inductance, while those at the top are nearer the open slot gap, and have less inductance. Consequently, current tends to flow more readily in the top strands. This unequal inductance may be eliminated by the method in which a coil is wound. If the first strand lies at the bottom, the second will be in the middle, and the third will be at the top. This process is carried out until the coil is completed. Another method of obtaining uniform current distribution is by twisting a stranded conductor. To insure that each strand offers a separate current path, the strands are coated with insulating enamel.

ROTARY FIELDS.—Rotating fields for a-c generators in general may be constructed in either of two ways. First, there may be a solid steel rotor in which the field windings are imbedded. Or, second, there may be a central steel frame to which separate laminated pole pieces are attached. The second type is the salient-pole construction, and is required by military specifications to be used in aircraft a-c generators. The use of this type construction permits a better power rating for a given generator, because the rotary field is more easily cooled. There is space for the passage of air between the salient poles, and their own inherent fanning action works to dissipate excessive heat. Heat is the greatest limiting factor in the rating of a generator. Military specifications also require that the field excitation power for a generator be produced within the machine itself. This keeps the a-c generator from being dependent on an external source for its d-c field. For this reason, a d-c exciter generator armature is built on the same driveshaft as the a-c generator's rotating field.

PHASING GENERATOR WINDINGS.—The two ends of each phase in an a-c generator are brought out to a pair of external terminals. Therefore, there are three pairs of terminal studs on the terminal block of a three-phase generator. These a-c terminals are the "T" terminals you will see when inspecting an a-c generator. Other terminals on the block are for exciter control. An attached plate will show internal connections for a particular generator so that you can determine which terminals constitute pairs, or opposite ends of each coil. By connecting short jumpers between the external

terminals of different phases, the generator may be made to operate in either delta or wye. Only the wye connection will be discussed, since naval aircraft generators are not operated in delta.

Assume that an inspection of the plate which shows internal connections indicates that paired terminals are *T*1 *T*4, *T*2 *T*5, and *T*3 *T*6, as shown in figure 6-11, and it is desired to operate a generator in a 4-wire wye system. Phase voltage is 100 volts. The first step is to connect a jumper between single ends of any two pairs of terminals, such as *T*1 and *T*2, with the generator running. A voltage reading taken across *T*4 and *T*5 should then be $100 \times \sqrt{3}$, or 173 volts. If it is only 100 volts, either coil must be reversed. Next, connect *T*3 to the junction of *T*1 and *T*2. Voltage checks from *T*6 to *T*4 and *T*6 to *T*5 should also read 173 volts. If not, the LAST coil connected (*T*5 *T*6) should be reversed. At this point, the wiring may be connected to the generator, observing the proper phase rotation. Terminals *T*4, *T*5, and *T*6 will connect to the phase power lines, and the common wire will connect to the junction of *T*1, *T*2, and *T*3.

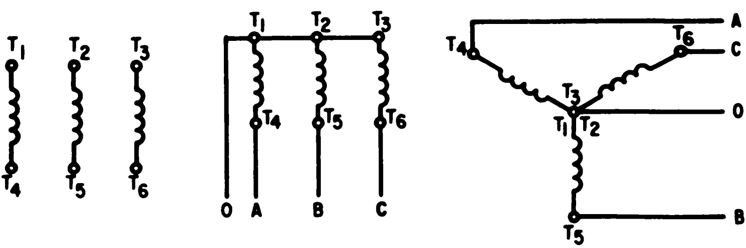


Figure 6-11.—Terminal connections.

A-C ELECTROMOTIVE FORCES AND OUTPUTS

Factors Affecting A-C Generator Terminal Voltage

When an a-c generator is operating properly, but with no load connected, the terminal voltage is the same as the voltage being induced into its windings. When a load is

connected, however, the resultant flow of current through the armature causes a number of things to happen. The net result of these operating characteristics is that terminal voltage assumes a different magnitude, and moves out of phase with the generator's fundamental induced voltage. One such characteristic is the resistive voltage drop across the armature.

ARMATURE RESISTANCE.—When current flows through the armature conductors, each conductor is surrounded by a resultant magnetic flux. The flux of all the conductors in a slot becomes linked into a single larger magnetic field. This flux flows freely in the low-reluctance iron surrounding the slot, and is referred to as leakage flux. It is an alternating flux, and results in eddy currents and hysteresis; these affect the iron by causing it to heat. These local losses vary nearly as the current squared, and so closely resemble losses caused by the simple copper ohmic resistance. Their effect is one of increased resistance, and accounts for a greater effective resistance to alternating current flow than to direct current. In practice, the total resistive (heat) loss in an armature is extremely small when compared to losses caused by armature reactance and armature reaction.

ARMATURE REACTANCE.—Because there are excellent linking conditions for conductor leakage fluxes, the inductive reactance of generator windings is very high in relation to their effective resistance. The combined loss caused by the effective resistance and inductive reactance is commonly referred to as the armature impedance loss, or synchronous impedance.

ARMATURE REACTION.—When there is no current flowing in the generator armature, there are no opposing or distorting influences working against the air-gap flux supplied by the field. With the start of armature current flow, however, the armature conductors set up a magnetomotive force of their own, because of the current flowing through them. It is an alternating m.m.f., because its parent current is an alternating current. This m.m.f. is responsible for the inductive reactance of the armature. In addition, this same m.m.f. reacts with the field flux. It may only distort the field, or air-gap flux, or it may directly oppose and materially weaken it. If conditions are right, it may even aid and strengthen the

air-gap flux. In any of these three cases, however, it obviously has definite effects on terminal voltage. The effect that the alternating armature m.m.f. has on the air-gap flux is determined by its timing in relation to the moving field poles. Its timing is determined by the reactive characteristic of the generator's load. This may be resistive, inductive, or capacitive. The effects of each type load are discussed.

Figure 6-12 shows the various effects caused by different reactive-characteristic loads. Part (A) represents a generator whose armature e.m.f. and current are in phase. E.m.f. is at its peak value because the coil sides are directly under the field poles. Since current is in phase, then the coil m.m.f. is also at its instantaneous peak simultaneously. Note that the effective center of the coil m.m.f. is acting on the space between the field poles. Therefore, the pole flux is distorted somewhat, but not materially weakened.

In (B), a highly inductive load is connected to the generator, so that current lags the coil e.m.f. by 90°. Peak induced e.m.f. occurred 90° before the instant shown, when coil side A was under a north pole. Peak m.m.f. exists 90° later, as shown. As a result of this timing, the peak magnetomotive forces of the coils occur directly under the field poles and are of opposite polarity to them. As a result, the air-gap flux is materially weakened, and output voltage is reduced. In (C) a capacitive load is connected to the generator, so that current leads the coil e.m.f. by 90°. Note in part (C) that conditions which existed in coil side A 90° after peak e.m.f. occurred in (B), now exist 90° before peak e.m.f. occurs. Again, as a result of this timing, peak coil m.m.f. occurs directly under the field poles. However, with current leading, the coil m.m.f. aids the field pole flux, and a greater induced voltage results.

From the foregoing, it can be seen that three major factors affect the terminal voltage of an a-c generator. For a fixed magnitude of load current, the armature resistance loss (IR) and armature reactance loss (IX) are fixed, regardless of load reactive characteristics. However, the effects of the third factor, armature reaction, depend greatly on load characteristics. The vector diagrams in figure 6-13 show how various load characteristics tend to affect terminal voltage.

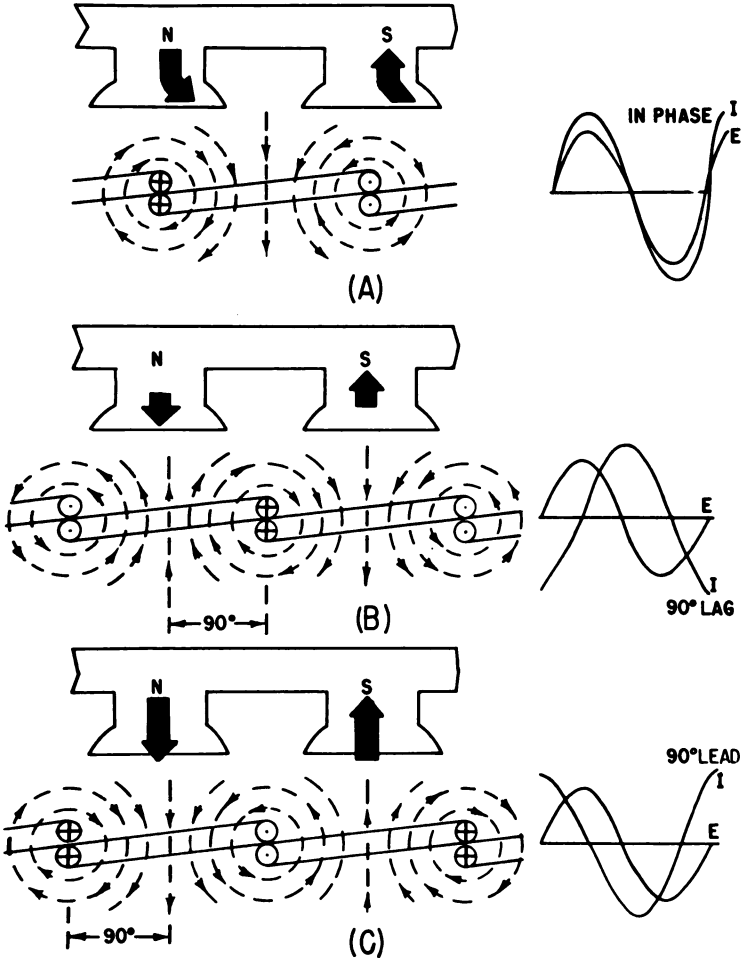


Figure 6-12.—Effects of load on air-gap flux pattern.

The word tend is used because terminal voltage is controlled and fixed by the voltage regulator. Since terminal voltage is held constant, then the variable quantity is the fundamental induced voltage. Changes in induced voltages are accomplished through changes in the magnetic strength of the rotating field. Figure 6-13 (A) depicts a generator whose internal winding reactance is X_L and whose winding resistance is R. The load is

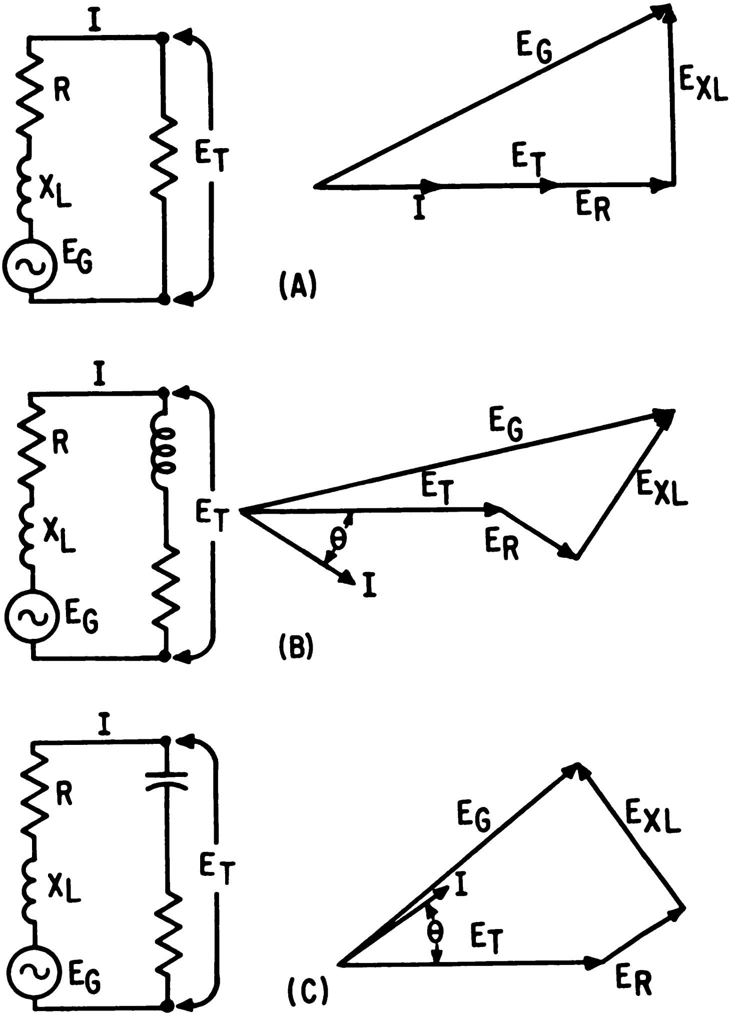


Figure 6-13.—(A) Resistive load; (B) inductive load; (C) capacitive load.

resistive, so terminal voltage E_T and line current I are in phase. The fundamental induced voltage E_G must be the vector sum of terminal voltage plus the internal drops E_{XL} and E_R. This is shown in the vector diagram. Note that the armature resistance drop E_R is in phase with the current, because it is a direct result of that current.

The reactance drop E_{XL} is laid out 90° leading, as usual. Total induced voltage E_G is the hypotenuse of a triangle whose base is E_T and E_R, and whose altitude is E_{XL}.

In (B), the magnitude of load current I is the same, but it now lags E_T by $\theta°$, due to the inductive load. The magnitude of E_R and E_{XL} has also remained unchanged. However, by remaining in phase with or following the current, E_R has tilted the winding impedance loss triangle so that E_G was required to increase its length in order to allow E_T to remain constant. What this amounts to, when applied to actual generator operation, is that the inductive load caused the timing of the armature m.m.f. to weaken the field flux. The voltage regulator then caused a greater field current, and thus increased E_G in order to hold E_T constant. It is to be noted that the magnitude of load current is the same in (A) and (B), yet a greater field control power was required when an inductive load replaced the resistive load.

In figure 6-13 (C), a capacitive load is connected, so that line current I leads terminal voltage E_T by $\theta°$. Again, E_R follows the current direction, and the winding impedance loss triangle is tilted so that E_G became shorter in order to maintain E_T at a constant length. That is, the armature m.m.f. timing was shifted to lead the coil e.m.f., and thus it aided and strengthened the field flux. The voltage regulator had to decrease field strength to prevent E_T from rising. Again, it is to be noted that current phase, not magnitude, was changed. It is also of interest to note that with enough capacitance in the load, the generator's induced e.m.f. may actually be less than its terminal voltage. Induced e.m.f. and terminal voltage are approximately equal when the load capacitive reactance matches the armature winding inductive reactance.

A-C Generator Inherent Regulation Characteristics

As you have probably realized from the foregoing, the inherent or self-regulating characteristics of an a-c

machine are poor when compared to a d-c machine of comparable rating. That is, should equal loads be placed on both generators, holding field strength constant, the a-c generator voltage would undergo a greater change than would the d-c generator's voltage. This characteristic is due to the a-c generator's greater sensitivity to armature reaction.

If the generator's tendency is toward large terminal voltage changes with changes in load, then its voltage regulator must obviously have a large range of control in order to maintain a-c terminal voltage at the desired value. The range of field power requirement is so great in some cases that the a-c voltage regulating system is designed with two separate ranges. This type of two-stage control is especially necessary where the voltage control of an a-c generator is further aggravated by a wide range of generator speed (variable-frequency systems). There would obviously be a very large difference in field power (current) in a generator operating at high speed with a small load, and one operating at a low speed with a heavy load. The exciter control relay shown in figure 6-14 enables the voltage regulator to maintain the proper a-c terminal voltage under both extreme conditions.

Under high-speed low-load conditions where less a-c field power is required, resistor *R*1 is in series with the a-c field. Contacts *C*1 and *C*2 are open. Starting with this condition, assume that the a-c load is increasing and the generator's r.p.m. is decreasing. The voltage regulator will cause the exciter armature output to rise, and current to increase through *R*1, the series coil, and the a-c generator field. At this time, the series coil attempts to close contacts *C*1, but cannot do so unaided. When the field current becomes high enough, the voltage drop across *R*1 becomes great enough (depending on the setting of *R*2) to operate the pilot relay, closing contact *C*2. When contact *C*2 is closed, the shunt coil is connected across *R*1, and its magnetomotive force aids the series coil, thus closing contacts *C*1. Contacts *C*1 shorts out *R*1, permitting full exciter power to be bypassed around *R*1 and applied to the a-c generator field. At this time, the pilot relay coil is also shorted, and contacts *C*2 open, which also deenergizes the shunt coil. However, the

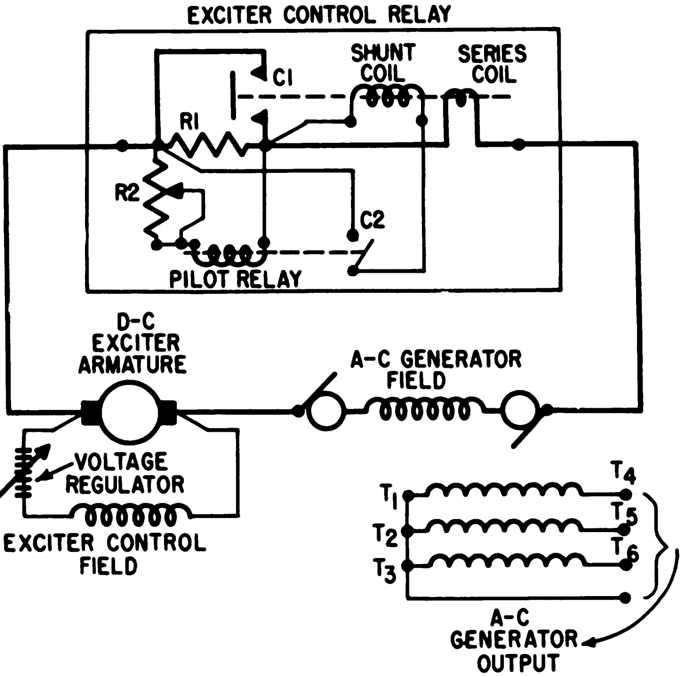


Figure 6-14.—Exciter control relay.

series coil is able to hold contacts C1 closed once it has been aided in getting them closed. Contacts C1 will remain closed until the field current decreases to the drop-out value at which the series coil can no longer hold them closed. Though the exciter control relay is not connected directly into the exciter field regulator circuit, its effect is to give the voltage control system as a whole a two-stage range.

The inherent regulation of an a-c generator is the change in voltage from full load to no load, holding field strength and r.p.m. constant, expressed as a percentage of full-load voltage.

$$\text{Percent regulation} = \frac{E_{NL} - E_{FL}}{E_{FL}} \times 100.$$

A-C GENERATOR PRIME MOVER CHARACTERISTICS

Single Generator Operation

The prime mover of an a-c generator is its source of rotational force. This force may be supplied directly by the aircraft engine, an air or gas turbine, a hydraulic motor, or an electric motor (as in the case of inverters). Whatever driving device is used, any power taken from the a-c generator ultimately is supplied by the prime mover. Therefore, the power rating of the driving device must be sufficient to supply the generator output energy, plus all losses, without excessive speed reduction. The governor of the prime mover must maintain driveshaft speed, with and without load, within the limits specified by the a-c generator's output frequency requirements.

Frequency and power controls are discussed later in this chapter.

Multigenerator Operation

In order for a-c generators to operate properly in parallel, their respective prime movers must have drooping speed-load characteristics. That is, their driving devices must undergo slight decreases in r.p.m. as load is added to the generators. This requirement exists for the following reasons.

The sloping, or drooping load lines shown in figure 6-15 show the effects on the speed of the two generators' prime movers as the common load is varied. Prime mover speed is given as generator frequency. Starting with a no-load condition, prime mover speed, and thus generator frequency, is at a maximum value, shown as F_{NL}. As load is increased from the no load to the operating-load condition, the speed of both prime movers decreases until line frequency is at F_{OL}. An increase of load current to a full-load condition would result in a line frequency of F_{FL}. It is assumed that both prime movers have identical speed-load characteristics, so it follows that each generator carries one-half of the total load. The terminal voltage and frequency of both generators

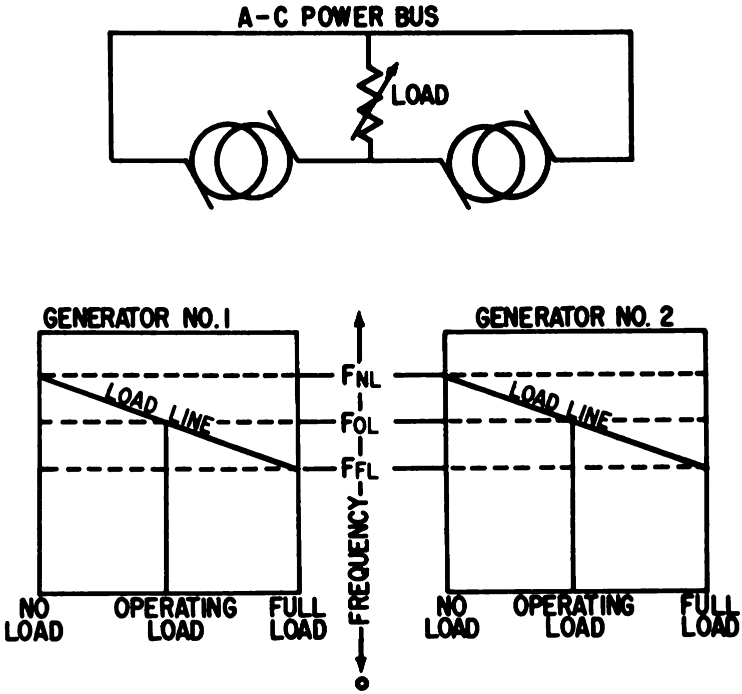


Figure 6-15.—Speed-load curves for a-c generators operating in parallel.

must always be the same, because their terminals are connected directly together on the a-c power bus.

When a generator is operating at a certain speed with a certain load, its prime mover is delivering all the mechanical power of which it is capable with that governor setting. If it were capable of delivering any more power, it would obviously speed up. Keeping this in mind, consider the following: Assume the two generators in figure 6-15 are supplying equal parts of a normal operating load, at a frequency of F_{OL}, and at a certain line voltage. To start with, the field strength of both generators is equal. If the field current of generator No. 1 is increased, and that of generator No. 2 is decreased a like amount, line (terminal) voltage remains the same, because the increasing voltage tendency of No. 1 is counteracted by the decreasing tendency of No. 2. At a glance, it would seem that generator No. 1 would assume

a greater load than generator No. 2, as would be the case if d-c generators were used. At this point, however, it must be remembered that the prime mover of generator No. 1 cannot assume any greater load. Likewise, the prime mover of generator No. 2 cannot drop any of its load, because there is no other device in the system to assume the load that is dropped, since generator No. 1 cannot do so. Therefore, it becomes apparent that **THE BALANCE OF POWER BETWEEN TWO A-C GENERATORS CANNOT BE EFFECTIVELY CONTROLLED BY CHANGES IN THEIR FIELD STRENGTH.**

A-C GENERATORS OPERATED IN PARALLEL

Reactive Power

It has been stated that changing the field strength of two generators operating parallel does not effectively change their power loads. It does, however, have certain other effects.

Figure 6-16 shows what these effects are. To begin with, part (A) represents two identical a-c generators operating in parallel whose terminal voltages are necessarily the same, and whose internal losses E_R and E_{XL} are identical. Field strength is the same in both generators, so their induced voltage E_G is the same. The load is nonreactive, so current I is in phase with terminal voltage E_T in both generators. In part (B), the field strength of generator No. 1 is decreased, and that of No. 2 is increased so that E_T is still the same. However, the induced voltage E_G has been forced to change in both generators because it is a function of field strength magnitude. For unequal induced voltages to result in equal terminal voltages, their vectors shift as shown in (B). Current leads in the underexcited generator, and lags an equal amount in the overexcited generator. Because of this change in the timing of the individual generator currents, the armature reaction (m.m.f.) of generator No. 1 is advanced and so does not adversely affect its air-gap flux as strongly as before. On the other hand, the armature m.m.f. is retarded in generator No. 2, and has a greater demagnetizing effect on air-gap flux than before. The net result is that the unequal induced voltages,

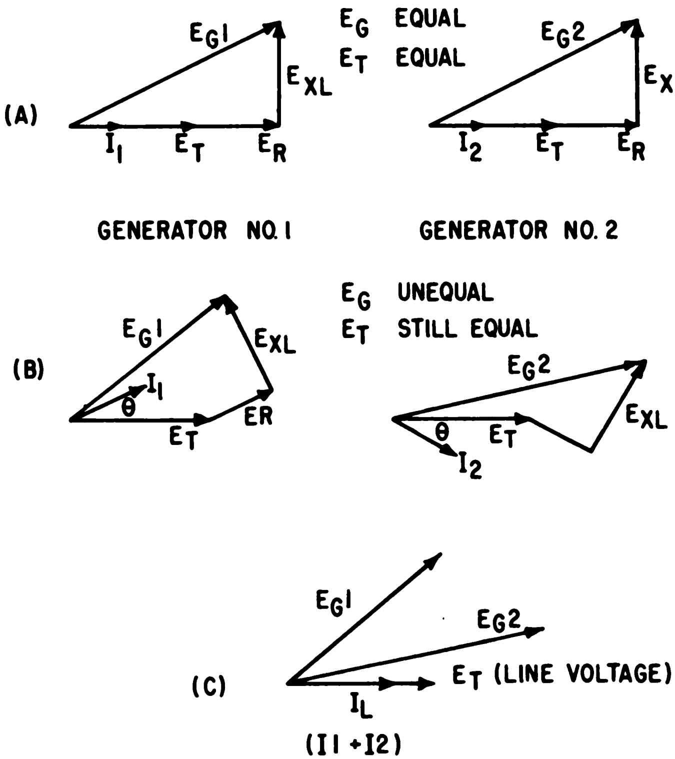


Figure 6-16.—Effects of varying field strength in generators operated in parallel.

due to the inverse and unequal effects of armature reaction, result in a common equal terminal voltage. It has developed, then, that the only visible effect of varying the generators field excitation is that current has moved out of phase with terminal voltage in both generators.

Where current leads in one generator, it lags an equal amount in the other, so power is still the same in both generators. It should be noted that these phase angles are NOT caused by a reactive load. Current through the load is in phase with line voltage, because load current is the sum of the two generator currents. This is shown in figure 6-16 (C). Since the generator currents lie in opposite directions an equal number of degrees away from line (terminal) voltage, their sum current phase

angle across the load is zero. However, it should also be noted that any reactive characteristic in the load would affect individual generator phase angles still further. For instance, an inductive load (due to its retarding effect) would decrease the current lead in generator No. 1, but would increase the current lag still further in generator No. 2. IT BECOMES APPARENT AT THIS POINT THAT WHERE THE LOAD IS UNAVOIDABLY REACTIVE, THE VARS SUPPLIED BY EACH GENERATOR IS MOST EFFECTIVELY CONTROLLED BY CHANGING THE FIELD STRENGTH OF THE GENERATORS. An equal distribution of reactive load (equal generator current phase angles) is obtained by changing the voltage regulator settings.

Watt Distribution

Figure 6-17 will be used to represent the sequence of reactions in two a-c generators operating in parallel when

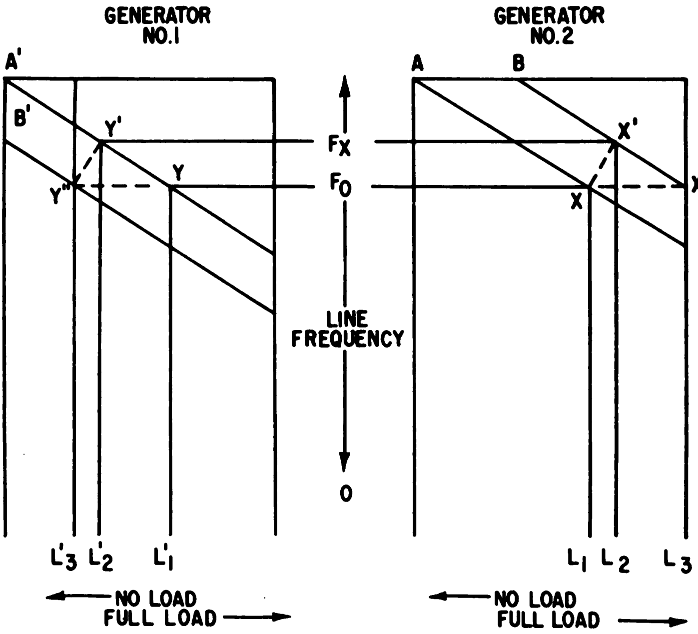


Figure 6-17.—Effects of varying prime mover governor settings.

adjustments are made to their prime mover governors. It is assumed both prime movers have identical power capacities.

At the start, the generators have equal in-phase current loads, and their speed-load curves (governor settings) A and A' are set at the same level. The line frequency is F_O, and the equal loads are L_1 and L_1'. The frequency line and load lines intersect the speed-load curves at point Y in generator No. 1 and at point X in generator No. 2.

Assume that it is desired to increase the load on generator No. 2 and decrease the load on generator No. 1, with no change in frequency. By increasing the governor setting on No. 2, its speed-load curve is raised to the level shown at B. The generator speeds up, bringing generator No. 1 up with it. (The reason for this is explained in this chapter under synchronizing power.) Line frequency is thus increased from F_O to F_X, and since the point of intersection has moved from X to X' in generator No. 2, the load has increased from L_1 to L_2. The speed-load setting for generator No. 1 was not changed, but the rise in line frequency moved its point of intersection from Y to Y', and decreased its load from L_1' to L_2 .

Since no change in frequency is allowed, the next step is to get the frequency from F_X back down to F_O. This is done by decreasing the governor setting on generator No. 1 and thus lowering its original speed-load curve from A' down to B'. The frequency F_X decreases to its original value of F_O, and the point of intersection in generator No. 1 moves from Y' to Y'', while its load decreases even further, from L_2' to L_3'. Simultaneously, the point of intersection in generator No. 2 moves from X' to X'' and its load increases even further from L_2 to L_3. At this time, the adjustments are complete. The final value of line frequency is unaltered, but the load on generator No. 2 has been increased from L_1 to L_3 while the load on generator No. 1 has been decreased from L_1' to L_3'.

From the foregoing, it is apparent that the most effective means of balancing the real load, in watts, between two a-c generators is through control of their prime mover mechanical power outputs. This is accomplished by controlling the governor settings on mechanical drives, or by varying the field strength of electric-motor drives.

From the foregoing discussion of reactive load balancing and watt load balancing, it becomes apparent that both a generator's voltage regulator and its prime mover governor serve dual purposes when the generator is operated in parallel with another. Their voltage regulators serve to control both line voltage and the reactive load balance between them, while their prime mover governors serve to control both line frequency and the watt load balancing. These functions may be accomplished either manually, or automatically.

Synchronizing Power

When two different generator phases are connected to a common bus, their alternating terminal voltages must be exactly in phase and of the same magnitude. Each phase voltage must reach its positive peak, negative peak, and zero value at exactly the same time as the other. Assuming these conditions exist, and no load is connected to the bus, then there will be no current flow through either generator. However, if any influence causes one generator to speed up, such as an increase in its prime mover governor setting, the other generator will also speed up.

This occurs for the following reason. When the first generator is accelerated, its alternating voltage timing is advanced slightly ahead of the other. Consequently, its phase voltage reaches its peak and zero values slightly ahead of the other. As a result, a circulating a-c current flows across the bus and through the generators. Its effect is to slow the speeding generator by loading it and to accelerate the lagging generator by tending to motorize it. With no load on the bus, the faster generator actually drives the slower one to some extent, allowing its prime mover to speed up. Where the two effects balance, a common and higher frequency is reached.

When a load is on the bus, the overdriven generator will not motorize the other, but will take more of the load and thus limit its own increase in speed. The underdriven generator will accordingly take less load and speed up to match the frequency of the faster generator.

This interaction is referred to as the synchronizing characteristics of a-c generators, and is responsible for their strong tendency to remain locked in when operated in parallel.

Required Conditions for Paralleling A-C Generators

Up to this point, the discussion has dealt with the operating and regulating aspects of a-c generators after they have been connected to a common bus. No mention has been made of the special requirements to be observed before connecting an additional a-c generator to a bus already being supplied by another.

In the parallel operation of d-c generators, a significant aspect to consider is that two generators with slightly unequal voltages, and whose armature r.p.m.'s are slightly unequal, may be connected to a common bus without damaging the generators. The two d-c generators will divide the load between themselves so that their terminal voltages (bus voltages) are equal. At this time, their individual speeds and loads may still be unequal. From the foregoing, it is apparent that the transient synchronizing forces which act on two generators when they are interconnected produce equal terminal voltages in all cases, but speed and load may remain unequal in d-c generators.

When a-c generators are operated in parallel, however, only the loading may be unequal. Frequency (electrical speed) and voltage must both be equal. Where synchronizing force was required to equalize only the voltage between the d-c generators, these forces are required to equalize both voltage and speed (frequency) between two a-c generators. Therefore, on a comparative basis, the transient synchronizing forces for a-c generators are much greater than for d-c generators. When a-c generators are of sufficient size, and are operating at unequal frequencies and terminal voltages, severe damage may result if they are suddenly connected to each other through a common bus. To avoid this, the generators must be synchronized as closely as possible before connecting them together. This is done by connecting one generator to the bus (referred to as

the bus generator), and then synchronizing the other, or incoming generator to it before closing the incoming generator's main power contactor. The generators are synchronized when the following conditions are set:

1. Equal terminal voltages. This is obtained by adjustment of the incoming generator's field strength.

2. Equal frequency. This is obtained by adjustment of the incoming generator's prime mover speed.

3. Phase voltages in proper phase relation. (Connecting phase voltages must reach peak values at the same instant.) The generators could have the same frequency, and still not be in step. That is, if the two generators have the same frequency, but one is lagging the other, the lagging generator will remain a fixed number of degrees behind the leading generator, until it is accelerated slightly to catch up.

4. Phases connected in proper sequence. One pair of phases may be properly connected, while the other two pairs may be crossed. In this case, the phase sequence of one generator may be ACB, while the other is ABC.

SYNCHRONIZING A-C GENERATORS.—All of the foregoing conditions may be set by the following methods.

Equal voltages may be checked by using a voltmeter. The remaining conditions, equal frequency, phase relations, and phase sequence, are checked by using synchronizing lamps. There are a number of ways in which synchronizing lamps may be connected, but the most satisfactory arrangement is the two-bright one-dark method. This connective arrangement is shown in figure 6-18. Note that the lamps are connected directly between the incoming generator's output and the buses. In this way, the two a-c sources may be synchronized before the incoming generator's main power contactor is closed.

Assume that the incoming generator is far out of synchronism, lagging. All three lamps will appear to glow steadily, because the frequency of the voltage across them is the difference in the frequencies of the two generators, and thus is too high for individual alternations to be observed. As the lagging generator is accelerated, however, the lamp (differential) frequency decreases until their light flickers visibly. Their flickering will have a rotating sequence, if connections are correct, and will indicate which generator is faster.

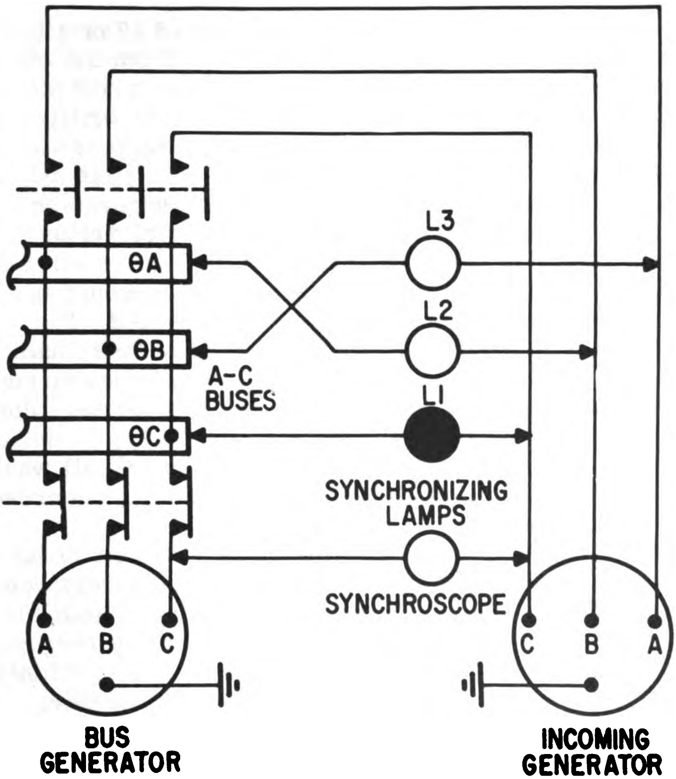


Figure 6-18.—Synchronizing lamp connection for two-bright one-dark method.

At a point approaching synchronism, lamp $L1$ will be dark because it is connected between like phases. That is, the two phase C voltages will be so nearly synchronized that their differential voltage across $L1$ will be insufficient to make it glow visibly. However, this differential is still of sufficient magnitude to damage the generators should they be connected at this time. The reason for cross-connecting $L2$ and $L3$ is now indicated. Under perfectly synchronized conditions, the phase voltages across $L2$ and $L3$ are both 120° apart, because of their cross-connection, and both glow with equal brilliance. However, if the generators were not in complete synchronism, but only very near it, the small angular

phase difference would add to the voltage of $L2$ or $L3$ (depending on phase sequence) and subtract from the other. This relatively small difference in voltage, undetectable in $L1$, would cause a visible difference in the brilliances of $L2$ and $L3$. Thus, by adjusting the incoming generator's frequency, and setting $L2$ and $L3$ so that no visible difference of brilliance exists, the generator frequencies and phase rotations may be synchronized very closely.

In addition to checking frequency, the lamps will also indicate improper phase sequence, such as would occur if the generators were improperly connected. For instance, if the conductors were crossed at terminals A and B on either generator, $L2$ and $L3$ would then be connected between like phases, just as $L1$ is already connected. Consequently, all lamps would flicker in unison as synchronized frequency was approached, and all would finally grow dark simultaneously, indicating incorrect phase sequence.

If a conductor from terminal A or B were crossed with C at either generator, then all three lamps would be connected between unlike phases. As a result, they would all flicker in unison as synchronized frequency was approached, and all would finally flow with equal brilliance, which would also indicate incorrect phase sequence.

In addition to the foregoing, it is possible that the two generators have exactly the same frequency, as indicated by a stationary synchroscope rotor, be connected properly, and yet have the wrong lamp dark. Should this happen, however, it merely indicates that one generator is exactly 120° behind the other. This condition is easily corrected by slowing the incoming generator momentarily, until the proper lamp is dark and the other two are of equal brilliance.

When the lamps have been used to get the generators as nearly synchronized as is visibly possible, the synchroscope, being a highly frequency-sensitive instrument, may be used to make the final fine adjustment to the incoming generator's frequency.

After all the foregoing checks and adjustments are made, the incoming generator's main power contactor may be closed, with very little disturbance on the line. If the bus generator is supplying a load when the incoming generator is connected, the incoming generator

should assume approximately one-half that load, provided the generators and their prime movers are of identical types and rating. The bus generator's voltage and frequency will tend to rise at the loss of load, but the incoming generator's voltage and frequency will tend to fall when it assumes part of the load. As a result, bus voltage and frequency are unaffected. The only changes that take place occur in the prime mover governors and voltage regulators.

AUTOMATIC FREQUENCY CONTROL AND LOAD BALANCING

Automatic Frequency Control of A-C Generators

Until recent years, any demand for a constant-frequency a-c power supply in an aircraft was usually satisfied by one or more inverters. Constant-frequency delivered by an engine-driven generator was difficult to obtain, because of constant changes in the engine's speed. The problem of increased weight precluded for a time the use of a device to convert variable engine r.p.m. into a fixed generator-drive r.p.m. However, as the power demanded from fixed-frequency systems increased, the size of the inverters also increased. This trend continued until the weight of the inverters, plus the extra weight required in their d-c power supplies, became as great as the combined weight of the a-c generators and their constant-speed drivers. Thus, constant-speed engine-driven a-c generators were made feasible, and came into use. Since the introduction of constant-speed engine-driven a-c generators, one of the AE's new duties has been to become familiar with the frequency controls of these systems.

NONELECTRICAL FREQUENCY CONTROL.—In most instances, a-c generator frequency is controlled by a mechanical governor which controls the speed of the prime mover driving device. In these installations, electrical frequency sensing and correction is not used.

Where compressed air turbines are used, jet engine driving power is utilized in the form of compressed air taken from the compressor section of the engine. A-c generator speed is then controlled by the amount of air passed through the turbine. This type of drive is used on the F2H-3, F8U and A3D aircraft.

Another engine-powered and mechanically speed-regulated a-c generator drive is the type used on the A4D aircraft. This assembly consists of an engine-driven hydraulic pump and hydraulic motor. The assembly's input r.p.m. varies with engine speed. However, its output r.p.m. is held within a narrow speed range by the assembly's internal governor.

Though the foregoing types of drives are classed as constant-speed, they actually allow generator frequency to vary over an approximate 40-cycle range. One of the reasons that this comparatively wide frequency range is permissible is that none of the mechanically-controlled systems are operated in parallel. At the present time the only system in which a-c generators are operated parallel is in the P5M aircraft; in this installation frequency control is accomplished electrically. Other large aircraft, including the A3D and WV have more than one a-c generator, but their systems include no provisions for parallel operation. Instead, each generator supplies a separate bus with provisions for either generator to supply both buses should one generator fail.

ELECTRICAL FREQUENCY CONTROL.—When an installation must provide for parallel operation of its a-c generators, at least two additional features must be included which are not found in mechanically-controlled systems. Frequency must be automatically controlled within a very narrow range, and a manual frequency control must also be provided. These two features enable you to obtain close synchronization of the generators prior to connecting them in parallel. To fulfill these requirements, electrical frequency controls are employed. These type controls are used because they are inherently more sensitive to frequency changes than mechanical controls. An electrical type system is also more easily controlled from a remote location by use of a servo loop.

The schematic in figure 6-19 represents such a system that is in current use.

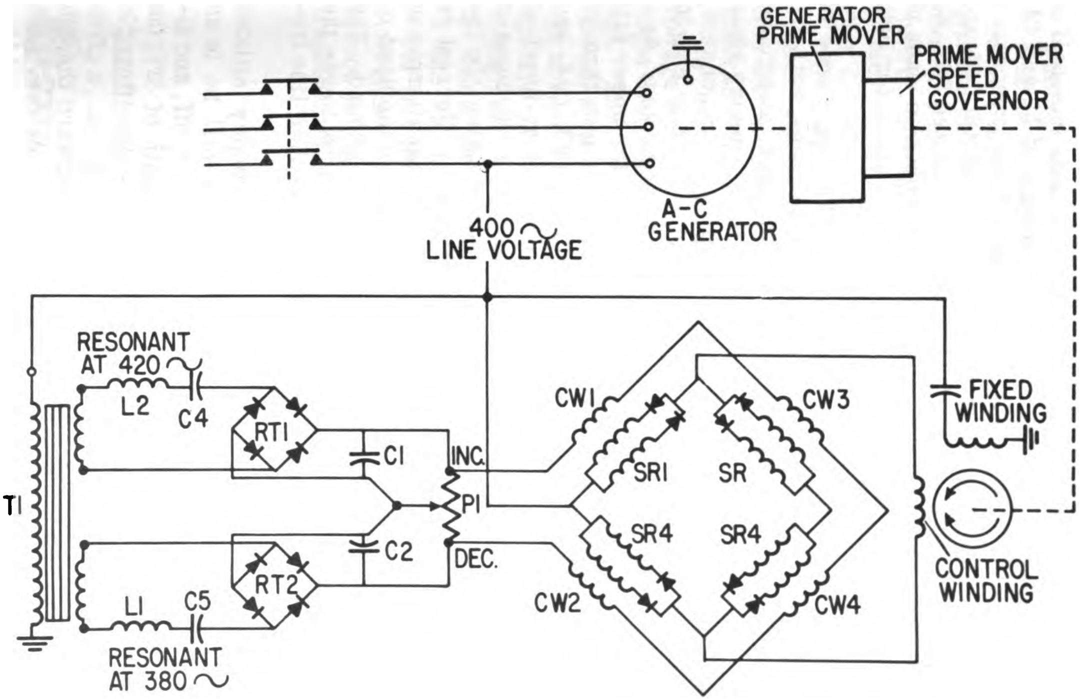


Figure 6-19.—Electrical frequency sensing and control system.

The line voltage, whose frequency is to be regulated, is connected across the primary of a transformer $T1$ which has two secondary windings. Each secondary circuit consists of a series circuit comprised respectively of an inductance, capacitance, rectifier, and one half of potentiometer $P1$. The series combinations of $L2$ and $C4$, and $L1$ and $C5$ are each 20 cycles away from resonance when the line frequency is 400 cycles. Capacitors $C1$ and $C2$ filter the ripple output of rectifiers $RT1$ and $RT2$, so that a smooth d.c. flows inward from opposite ends of $P1$. The center tap of $P1$ is a common return for both rectifiers.

When the frequency is 400 cycles, the impedance of $L1$ and $C5$ is equal to that of $L2$ and $C4$, because both are being subjected to a frequency that is 20 c.p.s. away from their resonant frequencies. Assume line frequency rises to 410 c.p.s. $L2$-$C4$ is now only 10 c.p.s. off resonance, so its impedance decreases. However, $L1$-$C5$ is now 30 c.p.s. off resonance and its impedance increases. As a result, a greater voltage appears across the upper half of $P1$ than across the lower half, and d.c. flows through the saturable reactor control coils $CW1$, $CW3$, $CW4$, and $CW2$. These coils are wound so that with a given direction of d.c. flow, their effect is to increase the inductance of the $SR1$ and $SR4$ load windings, while decreasing the inductance of the $SR2$ and $SR3$ load windings. Current is effectively cut off through $SR1$ and $SR4$, so that alternating current flows only through a series path comprised of $SR2$, the motor control winding, $SR3$, and ground. The resultant motor rotation is in a direction to lower the prime mover governor setting, and thus bring line frequency back down to 400 cycles.

If a drop, rather than rise, in line frequency initiates a control cycle, the control coil current will be in an opposite direction. $SR2$ and $SR3$ will be cut off, and alternating current will flow in the series path of $SR1$, the motor control field, $SR4$, and ground. It is significant to note that for a given direction of control coil d.c., a given alternation of applied line voltage will flow upward through the motor control winding. Had control coil d.c. been reversed, that same alternation would have flowed downward. Thus, the direction of the induction motor's field rotation, and consequently its shaft rotation, is controlled

by the direction of the saturable reactor control winding current. The direction of the control winding current is in turn controlled by line frequency.

The system just described is more sensitive, and maintains closer frequency control than any mechanical control system in current use. Thus, it fulfills the requirement of close automatic frequency control. It also provides the required means of remote manual frequency control. Manual frequency adjustments are made simply by moving the wiper of *P*1 away from the center, in whatever direction frequency must be changed.

AUTOMATIC REACTIVE LOAD BALANCING.—The system shown in figure 6-20 is designed to sense and correct an unbalanced reactive loading between two a-c generators.

Its basic operating concept is that the average d-c voltage across *R*1 will be directly affected by the phase angle between the generator's line current and line voltage. This system is VARS-sensitive. That is, when line current I_L and line voltage E_L are in phase, the voltage across *R*1 is minimum. When line current and voltage are farthest out of phase, as shown in figure 6-20, voltage across *R*1 is maximum. This effect results from the timing of the outputs from two different transformers *T*1 and *T*3, both of which are referenced to a common power supply (phase C in figure 6-20). The voltage reference is transformer *T*1, and the current reference is the current transformer *T*2. *T*3 is a coupling transformer.

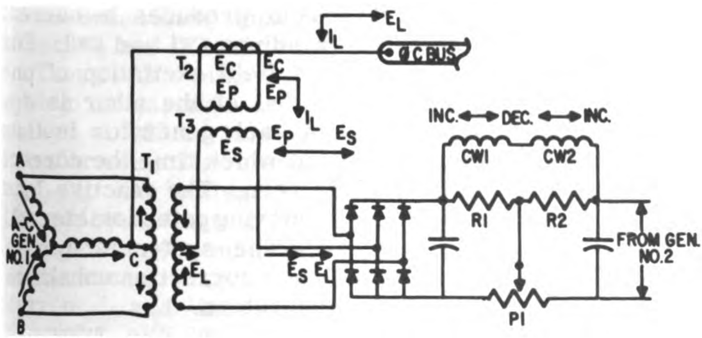


Figure 6-20.—Reactive load balancing system.

The output of $T1$ is fixed in relation to line voltage, regardless of where line current lays in phase relation. The output of $T2$, however, swings with line current, always lagging it by approximately 90°, regardless of where line voltage lays in phase relation. Thus, in figure 6-20, where I_L is assumed to be 90° out of phase with E_L, the output of $T2$ (E_c) and consequently the input of $T3$ (E_P) is 180° out of phase with line voltage E_L. Since $T3$ is a voltage transformer, its output E_S is shifted 180° from its input E_P. Through the foregoing steps, the original current-reference output E_C is shifted so that it comes out directly in phase with the voltage-reference output E_L. Their combined voltage E_SE_L can thus be seen to cause the greatest average rectifier d-c output across $R1$ when line current and voltage are farthest out of phase.

When line current swings more in phase with line voltage, this swing is reflected through the same sequence of steps so that E_S is moved out of phase with E_L, and the average d-c voltage is reduced.

Figure 6-20 shows the output of two such networks connected in electrical opposition to one another. They are connected in parallel with the control windings ($CW1$ and $CW2$) of two a-c generator voltage regulators. The voltage across $R1$ reflects the VARS being supplied by generator No. 1, and the voltage across $R2$ likewise reflects the VARS being supplied by generator No. 2. When the generators have equal line phase angles (regardless of angle magnitude), the current through $CW1$ and $CW2$ is zero. If the line phase angle of one generator becomes greater than that of the other, the result will be unequal voltages across $R1$ and $R2$. This produces a current through the voltage regulator windings $CW1$ and $CW2$. For a given direction of current, the field excitation of one generator is increased, while that of the other is decreased. The reactive load of each generator is thus shifted until the two are equal, at which time the current through $CW1$ and $CW2$ is again at zero. The reactive load may also be shifted manually by moving potentiometer $P1$.

WATT LOAD BALANCING.—The system shown in figure 6-21 is designed to sense and correct an unbalance of watt load between two a-c generators.

The system is watt-sensitive because the outputs of $RT1$ and $RT2$ across their respective halves of $P1$ are

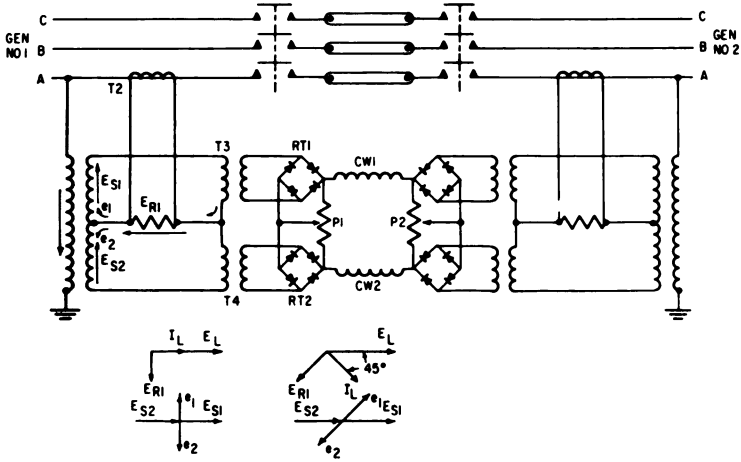


Figure 6-21.—Automatic watt load balancing system.

equal only when line current and voltage are in phase. This characteristic is achieved as follows. In the voltage-reference transformer *T1*, the secondary voltage E_{S1} and E_{S2} always act in the same direction, and are always of the same magnitude. If the current-transformer *T2* and its output E_{R1} were not in the circuit, the voltage and current in the primary windings of *T3* and *T4* would be equal. However, when the current-following voltage E_{R1} is connected as shown, its two components *e*1 and *e*2 act in opposite directions through the secondary windings of *T1*. E_{S1} is boosted, while E_{S2} is bucked. As a result, the primary voltage of *T3* is increased, and that of *T4* is decreased. This unbalance is reflected in their secondaries, and in their rectified d-c outputs.

Though *T2*'s output E_{R1} is constant, its effect on the system is variable as a function of its timing. E_{R1} is always at 90° to line current, because *T2* is a current transformer. Therefore, the timing, or phase relation, of E_{R1} to line voltage is determined by the phase relation of line voltage and line current. In the network, line voltage is referenced and represented by E_{S1} and E_{S2}. In the vector diagrams, it can be seen that when line current I_L and line voltage E_L are in phase, the voltages E_{R1} and E_L are 90° apart. When E_L is reduced to its components E_{S2} and E_{S1}, and E_{R1} is reduced to its components

$e1$ and $e2$, it can be seen that when they are 90° apart, there is no buck and boost action. However, when line current swings out of phase with line voltage, by 45° for instance, $e1$ is moved more in phase with E_{S1} while $e2$ is moved farther out of phase with E_{S2}. Thus the greater the line phase angle, the more pronounced is the unbalance in d-c output.

When two such networks are interconnected as in figure 6-21, unequal generator watt loads, indicated by unequal line phase angles, will result in unequal d-c voltages across $P1$ and $P2$. The resulting current flow through the saturable reactor control windings $CW1$ and $CW2$ will cause the watt loads to be balanced by causing the prime mover governor settings to be moved. Manual load balancing may be accomplished by moving potentiometer $P1$ or $P2$.

A-C VOLTAGE REGULATORS

Rectifier-Carbon Pile Regulators

Carbon-pile voltage regulators are given sufficient coverage in *AE 3 & 2*, NavPers 10348, and are not discussed in this chapter.

Static Regulators

A recent addition to the equipment which the AE is required to understand and maintain is the static a-c voltage regulator. As the word static indicates, there are no moving mechanical parts in the entire regulating mechanism (except for exciter control relays which operate only once, when initial generator voltage is built up).

The overall operating principles of static regulators are as follows. In accordance with the control exerted by the regulator, a certain amount of power is fed to the exciter's control field. The amount of power fed to the field is regulated by saturable reactors. (Saturable reactors are discussed in chapter 5 of this course.) Saturable reactor output to the exciter field is in turn controlled by the direction of the d.c. in the reactor's control windings. In turn, the magnitude and direction of control-winding current is determined by the magnitude and direction of imbalance of an ordinary d-c Wheatstone bridge. This bridge obtains its d-c power from rectifiers which are fed by the line a-c voltage to be regulated. Thus, the level of that

line a-c voltage is ultimately responsible for the amount of d-c power fed to the exciter control field.

The general operating principles just described apply to all static regulators currently in use. Various regulators differ, however, in some functions. For instance, one type employs two stages of magnetic amplification, where another has only one. The regulator discussed in this chapter is used on a late model naval aircraft. A careful study of its operation will be of help in understanding similar regulators used in other applications. The complete regulator used for this explanation appears in figure 6-23. However, the heart of the regulator, its voltage-sensing bridge circuit, is shown in figure 6-22.

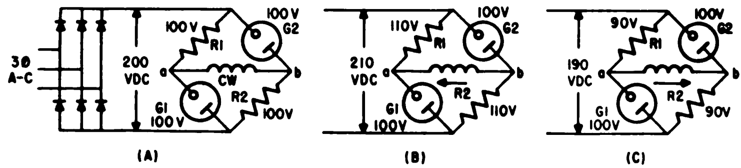


Figure 6-22.—Line voltage-sensing bridge.

BRIDGE CIRCUIT.—Figure 6-22 (A) illustrates the primary features of the voltage-sensing bridge circuit. The line a-c voltage is rectified to a nominal value of 200 volts d.c. and applied across a bridge consisting of *R*1, *G*1, *R*2 and *G*2. Resistors *R*1 and *R*2 are fixed resistors. Tubes *G*1 and *G*2 are of the gas-discharge type, commonly referred to as voltage regulator (VR) tubes. Since they possess only a cathode and plate, they are rugged and are not subject to the common causes of failure in ordinary electron tubes. The most important feature of these tubes, however, is their ability to maintain a constant voltage drop across themselves regardless of changes in applied rectifier d-c. The tubes used in figure 6-22 (A) maintain a constant drop of 100 volts. When line voltage is at the proper value, the d-c bridge voltage is 200 volts. The ohmic value of *R*1 and *R*2 is such that their voltage drops are the same as the voltage drops of the tubes. Under these conditions, the bridge is balanced and no current flows between points a and b through the control winding *CW*. In part (B), line voltage has risen to 210 volts. Since *G*1 and *G*2 cannot change

their drops, the increase of applied voltage appears across $R1$ and $R2$. Thus, the increase of applied voltage alone has caused an unbalanced bridge, and current flows from b to a. In part (C), where line voltage dropped to 190 volts, tubes $G1$ and $G2$ still have a drop of 100 volts. The decrease of applied voltage appears across $R1$ and $R2$, and the bridge is unbalanced in the opposite direction.

From the foregoing, it can be seen that the essential function of the bridge circuit is to translate a variation of line a-c voltage into a current through the control coil.

COMPLETE TYPICAL STATIC REGULATOR.—Figure 6-23 is a complete regulator, showing how the bridge sensor is connected.

A complete sequence of operation is as follows:

At the start, generator voltage is zero and relays $K1$ and $K2$ are in the positions shown. During the initial buildup of voltage, the residual d-c output of the exciter armature is connected directly to the exciter control field through terminal $A+$ and $K2$, through the lower winding of stabilizer transformer $T3$, and then through $F+$ to the field. This causes a rapid buildup of exciter voltage, and consequently a rapid buildup of a-c output voltage through $T1$, $T2$, and $T3$. When line voltage has risen to a near-normal level, the output of $CR1$ is sufficient to actuate relays $K1$ and $K2$. With the armature of $K2$ pulled down, exciter output no longer goes directly to the control field, but instead goes only through $T2$ to $A-$, and is used thereafter only as a stabilizer reference during normal operation. When the armature of $K1$ is pulled down, the output of $T1$'s secondary is routed through the load windings 3-4 of the saturable reactor $L1$ to rectifier $CR2$. $T1$ thus takes over the function of supplying power to the exciter control field. The output of $T1$ is rectified by $CR2$, and the d-c is routed from terminal X on $CR2$ through $T3$ and thence to $F+$ and the field.

The amount of power that $T1$ may ultimately pass to $F+$ is governed by the impedance of the series load windings 3-4 in $L1$. These windings' impedance in turn is regulated by the bridge-powered d-c control winding 1-2. The complete regulating loop can now be seen. A-c line voltage at $T1$, $T2$ and $T3$ acts through $CR1$ and $BR1$ into $L1$. This governs the output of $T1$ through $L1$, $CR2$, and $T3$ into the exciter control field. In turn, the exciter control field

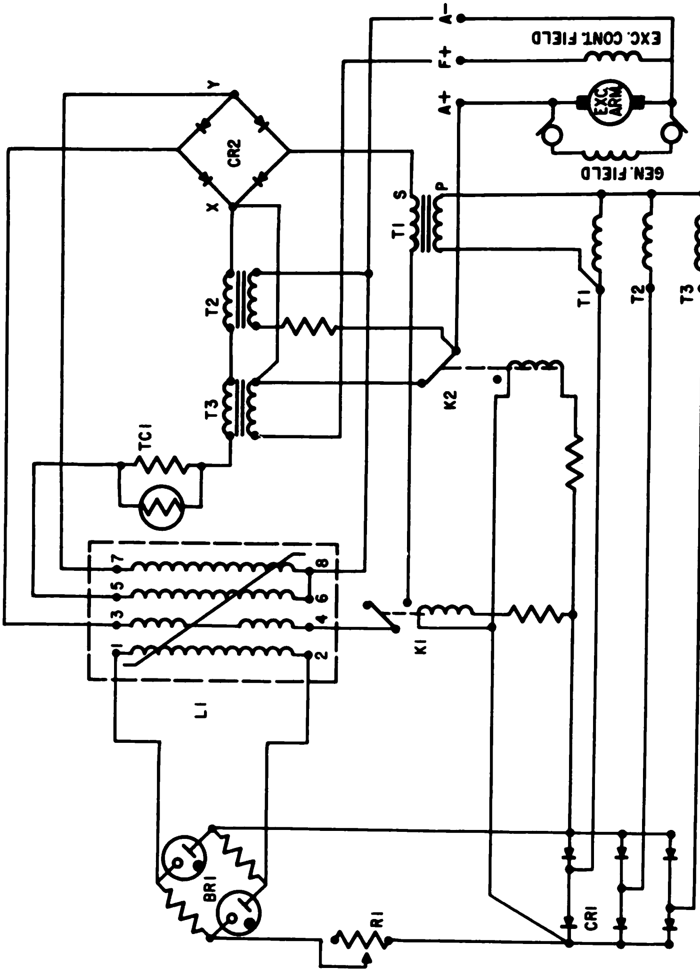


Figure 6-23.—Typical static regulator.

regulates the exciter armature voltage, and thus generator field strength, and finally the output a-c voltage at *T*1, *T*2, and *T*3.

From terminal *X* on *CR*2, d.c. is also routed through *T*2, *T*3, and the temperature-compensator *TC*1. This d.c. goes further for it flows downward through *L*1's winding 5-6, upward through winding 8-7, and finally back to its rectifier source at terminal *Y*. This circuit is used for biasing the saturable reactor *L*1 at the proper operating level.

Winding 8-7 serves an additional purpose. This is explained as follows. To make a complete circuit, exciter control field current must flow from *X* on *CR*2 through the lower winding of *T*3, through the field, and then back upward through *A*-, winding 8-7, and finally into terminal *Y* on *CR*2. Since the bias winding 8-7 is thus seen to be in series with the control field, then it follows that any variation in the control field current will also cause a variation in the biased output level of *L*1. An increase in control field current causes a decrease in *L*1's output, because of the way in which 8-7 is wound. Winding 8-7, therefore, is employed as a stabilizing negative-feedback winding, as well as for bias balancing. The same stabilizing effects are accomplished by transformers *T*3 and *T*2.

Voltage adjustment is made with *R*1. When *R*1 is positioned to increase the voltage applied across *BR*1, the bridge will immediately act to decrease line a-c voltage and the output of *CR*1 until bridge voltage is depressed to its original value.

VOLTAGE CONTROL OF INVERTERS

Carbon-Pile Inverter Voltage Regulators

Extensive coverage is not given carbon-pile type voltage regulators in this chapter. An inverter is basically a d-c motor-driven generator, and its a-c voltage is controlled in exactly the same manner as any other a-c generator where a carbon-pile regulator is employed. The only important difference is that an a-c generator provides its own d-c power for field excitation from within itself, where an inverter must depend on an external source for its field d-c.

Electronic Inverter Voltage Regulators

There are a number of electronically-regulated inverters, and detailed information for each may be found in the *Handbook of Overhaul Instructions* for the particular unit. The type of voltage regulator discussed here is used only as a typical example, though it closely resembles the type used in the Holtzer-Cabot D-139 inverter.

The main advantage of a purely electronic inverter voltage regulator is that it contains no moving parts, such as those in the carbon-pile regulator.

A regulator of this type is shown in figure 6-24. Its operation is as follows. One phase of the inverter voltage to be regulated is applied to transformer *T*3. The secondary output is half-wave rectified, so that the top secondary winding conducts through *V*1A on one half-cycle, and the bottom winding conducts through *V*1B on the other half-cycle. Filter networks *F*1 and *F*2 produce d.c. across both VR tube *G*1 and resistor *R*2. Any change in inverter a-c voltage is translated into a change in the average d-c voltage output of the filter networks. Any variation in the output of *F*1 appears across *R*2. However, since *G*1 maintains a constant voltage drop across itself, the equal and simultaneous variations in the output of *F*2 must appear across *R*1. The differential of the voltages across *R*2 and *G*1 is applied across the grid and cathode of *V*2. In a condition where inverter voltage is normal, the upper end of *R*2 is less positive than the lower end of *G*1. Consequently, the cathode sees the grid as being negative, because the cathode is more positive than the grid. The magnitude of the relatively negative grid voltage is such that *V*2 is operated class A. In this way, grid voltage, and thus tube conduction, can follow any variation in inverter voltage either above or below its normal level. Filter network *F*3 removes any ripple from the *V*2 grid voltage, but does not affect its magnitude. *R*3 is the voltage adjusting rheostat.

The voltage of *G*1 is also applied across the grid and cathode of the parallel tubes *V*3 and *V*4. This negative biasing is such that *V*3 and *V*4 are also operated class A. Variations in the conduction and plate voltage of *V*2 act through *R*4 and *R*5 to affect the conduction of *V*3 and *V*4.

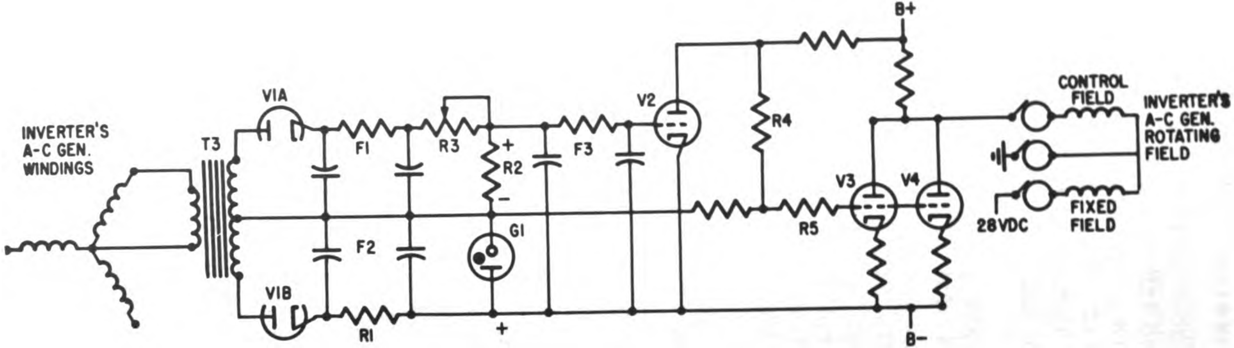


Figure 6-24.—Electronic inverter voltage regulator.

The steady-state B+ current flowing through the control field is varied as the plate voltage of *V*3 and *V*4 is varied. In summation, it can be seen that a decrease in the inverter's a-c voltage causes a decrease in the input voltage to *T*3. The result is an increase in the output through the control field, raising the output a-c voltage back to its original value.

Another type of voltage regulator is shown in figure 6-25. This type is used in the Leland SE5-1, SE5-2, SE8-2, and SE16 inverters. It is not a purely electronic regulator, because a carbon pile is employed to furnish the necessary current variations through the inverter's a-c generator field. Only the voltage error sensing and amplification is done electronically in this regulator.

The entire voltage of each alternation through secondary winding *S*1 is rectified by *V*1 and *V*2 and appears across *V*3 and *R*2. Secondary *S*2 is the voltage-sensor pickup, and heats the filament of *V*3. *S*2's output, governed by line a-c voltage, thus varies the filament temperature of *V*3 in accordance with line voltage. Variations of its filament temperature causes variations in the cathode electron emission, and consequently the conduction of *V*3. Therefore, the conduction of direct current and the plate voltage of *V*3 is controlled through *S*2 by the line voltage. Capacitor *C*1 stabilizes the regulator's operation by smoothing out changes of voltage across *V*3.

With a rise in line voltage, *V*3's conduction increases, and its plate becomes less positive. The grid of *V*4 must

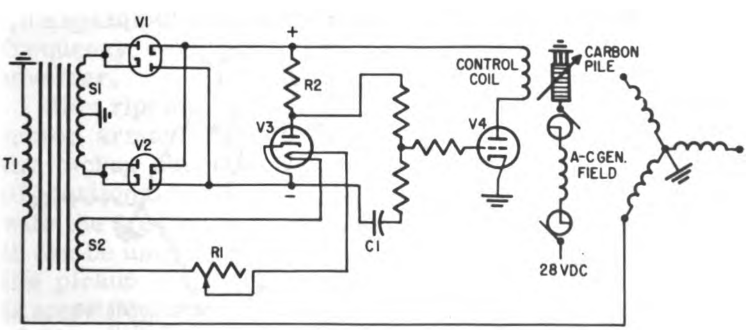


Figure 6-25.—Electronic carbon-pile regulator.

also become less positive, and therefore the conduction of $V4$ decreases. The resulting decrease of control coil current permits decompression and thus causes increased resistance in the carbon pile. When the generator field current is thus decreased, line voltage decreases to its original value. It will be noted that when this type regulator is used the carbon-pile resistance variation in relation to changes of control coil current is the reverse of what it is usually found to be. That is, in most carbon-pile regulators, a decrease of control coil current would cause a compression and decreased resistance in its carbon pile. Where coil magnetomotive force pulls an iron slug away from the stack in most regulators, the same magnetomotive force when applied in the Leland inverter presses an iron slug against the carbon stack. $R1$ is used for voltage adjustment.

A third type of voltage regulator appears in figure 6-26. This regulator is most similar to the ones used on Jack and Heintz inverters F138-1, 2, and F148-1, 2. It is essentially a rectifier-carbon pile regulator, but is given coverage here because it employs at least one electronic part. Its operation is as follows.

Inverter line a-c voltage is fed to transformer $T1$, rectified through $RT1$, and applied through the series circuit consisting of $R1$, the control coil, and the gaseous voltage regulator tube $OB2$. Resistor $R2$ is a voltage developer whose IR drop appears only across $OB2$ before it fires, and across $OB2$ and the control coil after it fires. When the inverter is first turned on, 28 volts d.c. is impressed unopposed across the control coil, and maximum current flows upward. This results in maximum pile compression,

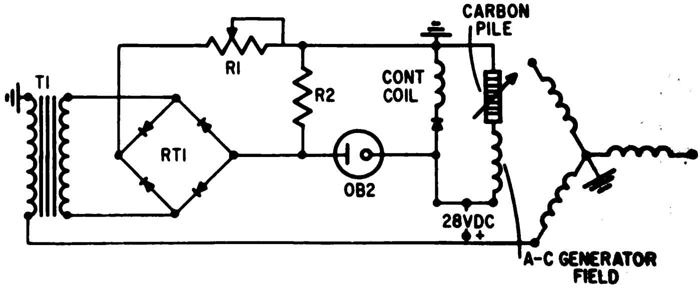


Figure 6-26.—Semielectronic inverter voltage regulator.

minimum pile resistance, maximum field current, and thus the most rapid buildup in a-c output. The rising a-c output appears across *R*2 and is impressed across *OB*2 in the form of a rising d-c voltage. When the magnitude of this d.c. is approximately 110 volts, *OB*2 fires, and thereafter its voltage is a steady 105 volts. The ultimate steady-state d.c. across *R*2 is 115 volts. With 105 volts across *OB*2, the remaining 10 volts act downward through the control coil, in opposition to the fixed 28 volts acting upward. Since the voltage across *OB*2 is fixed, any variations of line voltage, and thus d-c voltage across *R*2, varies the oppositional voltage acting through the control coil. Variations of the opposition encountered by the fixed 28 volts causes proportional variations in the control coil current, which the 28-volt source impresses through the coil. Control coil current affects the carbon pile's compression and resistance, and thus field strength, so that output a-c voltage is regulated. Voltage adjustment is made with *R*1.

FREQUENCY CONTROL OF INVERTERS

Flyweight Carbon-Pile Speed Regulators

Mechanical (flyweight carbon-pile) inverter speed regulation is discussed in *AE 3 & 2,* NavPers 10348, and is not discussed in this chapter.

Electronic Frequency Control

Figure 6-27 is a simplified drawing of the all-electronic frequency regulator used on the Holtzer-Cabot D-139 inverter.

Flux ripple in the motor frame, caused by the rotating motor armature, induces a small alternating voltage in the pickup coil *PC*. The frequency of this a-c voltage is proportional to the motor armature speed, and thus varies with the frequency of the main a-c output. Consequently, it can be used as an indication of output frequency. When the pickup coil a-c signal is applied to the grid of *V*1, it is amplified, and a rippling d.c. flows through the primary of *T*1, with a frequency the same as that coming from *PC*. An a-c voltage, still of the same frequency, is then induced into secondaries *S*1, *S*2, and *S*3.

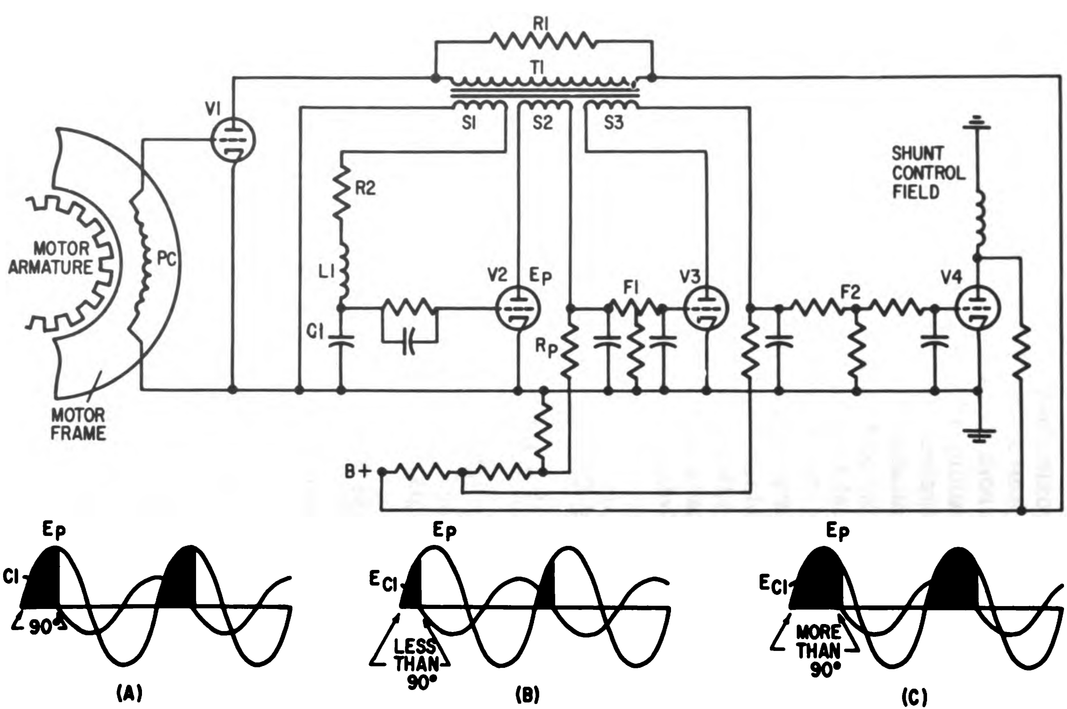


Figure 6-27.—All-electronic inverter frequency regulator.

When the main a-c voltage is at the proper frequency, the *PC* frequency in *S*1 will be the resonant frequency of the series combination of *R*2, *L*1, and *C*1. Under this condition, the voltage across *C*1 lags the voltage of *S*1 by 90°, but leads the voltage of *S*2, as felt on the plate of *V*2, by 90°. Thus, *V*2 is operated as a grid-controlled rectifier. In the sine wave diagram in figure 6-27 (A), it can be seen that when the voltage across *C*1 leads the voltage across *V*2 (E_P) by exactly 90°, tube *V*2 conducts for exactly one-half of each positive alternation of its plate voltage. The half-cycle of *V*2's plate voltage (E_P) during which conduction takes place is the shaded area shown in (A). Note that conduction takes place only when both sine waves lie on the positive side of their respective zero values.

If the inverter speeds up, the frequency across *R*2-*L*1-*C*1 goes above resonance for that circuit, and E_{C1} will lead E_P by less than 90°. The result, decreased conduction through *V*2, is shown in (B). If the inverter slows down, the frequency across *R*2-*L*1-*C*1 goes below resonance, and E_{C1} will lead E_P by more than 90°. The result, increased conduction through *V*2, is shown in (C).

The pulsating output of *V*2 across its plate resistor *RP* is filtered through network *F*1 and appears on the grid of *V*2 as a d-c voltage. This d-c voltage is the average of the pulsating voltage on the plate of *V*2. The magnitude of this d-c voltage on its grid affects the average conduction of *V*3 in the same way as the timing of an a-c voltage on its grid affected the conduction of *V*2. The output of *V*3 is filtered across network *F*2, and appears as a d-c voltage on the grid of *V*4. Thus, through the foregoing sequence, any change of inverter frequency results in a change of grid voltage at *V*4. Variations in the grid voltage of *V*4 causes variations in its conduction and plate voltage. These variations of *V*4's plate voltage cause changes in the d.c. through the inverter motor's speed controlling shunt field and will be in a direction to oppose whatever changes in motor speed initiated the regulating cycle.

The next frequency-regulating circuit to be discussed is one similar to that used in the Leland SE5-1, SE5-2, SE8-1, 2, and SE16 inverters. Before entering a discussion of that complete circuit, however, a portion of the

circuit should be discussed. This portion in highly simplified form is shown in figure 6-28.

Two a-c voltages, E_1 and E_2, are half-wave rectified through diodes $V1$ and $V2$ and applied across a common capacitor. The voltages are 180° out of phase, so each tends to charge the capacitor in the direction indicated by its arrow. If E_1 is of greater magnitude, as shown, the capacitor will be charged in the direction of the longer arrow, and with the polarity as marked. In the sine wave analysis, it can be seen that the peak charge (E_C) of the capacitor is the difference of peak E_1 and peak E_2, with those voltages exactly 180° out of phase. A variation in either voltage's magnitude or phase relation will result in a change in the capacitor's charge. The capacitor is charged to a peak value of E_1 minus E_2 on the positive alternations, but has no low-impedance discharge path between alternations. Consequently, its voltage decreases very little between peak charges. Its resultant steady-state average wave thus appears as the d-c voltage E_{AV} on the sine graph. Using E_{AV} as the control grid voltage on $V3$, the conduction of $V3$ is directly affected by any variations in the magnitude or phase relations of E_1 and E_2. For instance, if E_1 were decreased and E_2 were increased, their difference voltage E_{AV} would be reduced.

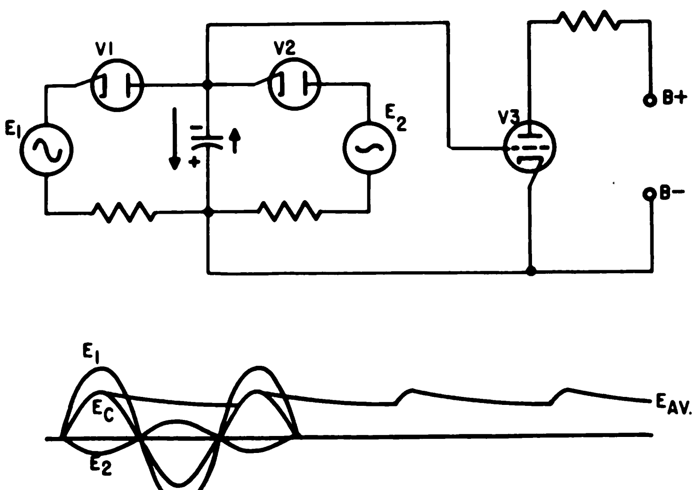


Figure 6-28.—Simplified portion of Leland frequency regulator.

The grid of $V3$ would become less negative, and $V3$'s conduction would increase.

All of the operating principles just discussed apply to the more complete frequency regulator shown in figure 6-29.

The regulator's operation is as follows. Transformer $T1$ is supplied by the inverter's line a-c voltage, and its output is in turn applied through $C1$ and $L1$. Inductor $L1$'s voltage (E_2) is impressed and half-wave rectified through diode $V1A$ and $C2$. Line a-c voltage is also applied through $P1$, and a portion of it is tapped off and routed through $R2$ and $C3$. Capacitor $C3$'s voltage (E_1) is impressed and half-wave rectified through diode $V1B$ and $C2$. Voltages E_1 and E_2 tend to charge $C2$ in opposite directions.

When the inverter is operating at the proper frequency (speed), the voltages E_1 and E_2 are 180° out of phase. Voltage E_1 is of greater magnitude, however, so E_{AV} across capacitor $C2$ has the polarity indicated. This condition is shown in vector diagram (A).

If inverter frequency rises, the inductive reactance of $L1$ increases and so does its voltage (E_2). Simultaneously, the capacitive reactance of $C3$ decreases, and so does its voltage (E_1). In addition, the two voltages move more than 180° apart, as shown in diagram (B). Had inverter frequency decreased, rather than increased, the

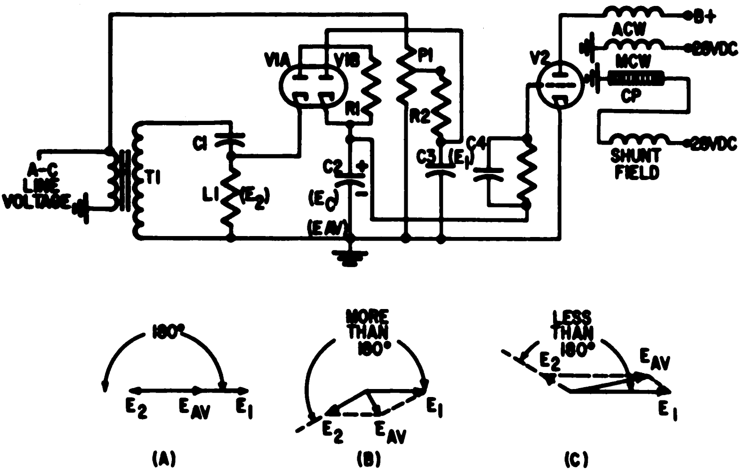


Figure 6-29.—Complete Leland inverter frequency regulator.

result would have been just the opposite in all respects, as shown in (C). Note that E_{AV} of the magnitude shown in (A) is decreased in (B), but increased in (C). Since E_{AV} is applied to the grid of *V*2, any change of inverter frequency results in a change of *V*2 conduction. Any change in *V*2's conduction varies the current through the auxiliary carbon-pile control coil *ACW*. Coil *ACW* is wound in magnetic opposition to the fixed main control coil *MCW*. Therefore, any variation in *ACW* current (*V*2 conduction) affects the two coils' differential magnetic force acting on the carbon pile *CP*. Variations of carbon-pile compression cause variations of shunt field strength, and result in corrective inverter speed changes.

A-C SYSTEM PROTECTION

With the incorporation of high-capacity a-c power systems in naval aircraft, there came the accompanying problems of protecting both the aircraft and its a-c system from a number of possible fault conditions. Such forseeable conditions included power feeder cables shorting to ground (ground fault), improper system voltage (voltage fault), and improper system frequency (frequency fault). A discussion of each type of fault will follow.

Ground-Fault Protection

PREVENTIVE GROUND-FAULT PROTECTION.—This type protection is basically in the realm of installation and design practices, aimed at preventing a ground fault from occurring in the first place. A few examples of preventive action are: adequate insulation and isolation of buses, insulated junction boxes, and extra insulation in critical areas. However, protection of a corrective nature must also be provided, because ground faults may occur despite all preventive measures.

CORRECTIVE GROUND-FAULT PROTECTION.—This type protection comes into use after a ground fault has occurred, mainly to prevent fire or damage to the aircraft. The primary function of protective networks or devices is usually to disable a faulted power system. However, some devices designed to provide this protection

also have a secondary feature; that of isolating only the damaged or faulty portion of a system, when possible, and thus permitting continued use of the undamaged portions. These may be referred to as dual-function devices.

Single-function devices do not permit continued use of the undamaged portions, but function only to disable and isolate an entire power system when a fault occurs anywhere in the system's protected portions. These portions include only the generator, its power feeder cables, and the bus to which it is connected. (Branch circuits coming off the bus have their own fuses and circuit breakers.)

The type of device to use in a particular a-c power system is dictated by the nature of the equipment supplied by that particular system. All such equipment must fall into at least one of the following categories:

1. Vital equipment required at all times to maintain controlled flight.

2. Equipment needed to perform the aircraft's mission, but not necessary for controlled flight.

3. Convenience equipment, not necessary for either (1) or (2).

Obviously single-function devices could not be used in systems supplying power for category (1) equipment. On the other hand, it would not be necessary to employ dual-function devices in systems supplying power for category (3) equipment. The choice of device for category (2) would depend on the importance of the aircraft's mission. An additional feature of both dual- and single-function devices and networks is their fail-safe design. This feature is incorporated wherever possible. If a protective device, circuit, or network is fail-safe, this means that the protected a-c power system will not be disabled, should the protective equipment itself fail.

Figure 6-30 illustrates two typical general methods currently employed to provide ground-fault protection. Both are designed fail-safe. Part (A) is a differential-relay single-function method, and (B) is a fuse mesh dual-function method. In (A), the two current transformer outputs are connected in opposition across the differential relay coil. If either the hot feeder cable or the ground feeder cable becomes grounded, then the currents through the two cables are unequal, and this will

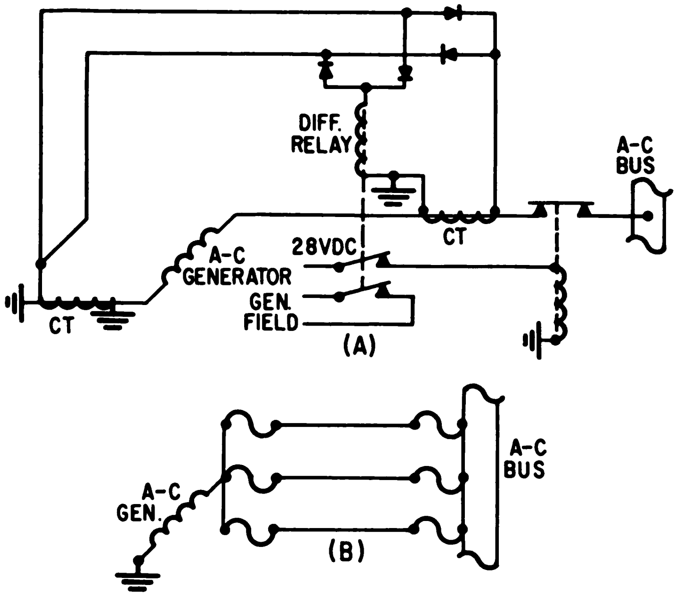


Figure 6-30.—(A) Single-function protector; (B) dual-function protector.

result in unequal current transformer output voltages. The differential of these voltages will operate the differential relay, which opens the generator field, and disconnects the generator's feeder cable from the bus. This method is fail-safe to the extent that if one or both of the interconnecting leads become either open or grounded, this protective circuit failure will not cause the generator to be disabled.

Part (B) of figure 6-30 is the dual-function method. If a ground fault occurs on any one of the three feeders, the fuses at the ends of the faulted feeder will open. This isolates only the faulted portion, while permitting continued use of the rest of the system.

Overvoltage-Fault Protection

Under normal conditions, system a-c voltage is controlled by the voltage regulator. However, to cope with forseeable voltage-fault conditions not controllable by the regulator, provisions for backup voltage-fault protection

are needed in a-c power systems. These provisions are made in a number of different ways, for different aircraft, and the best way to familiarize yourself with any certain method or device is to consult the *Handbook of Overhaul Instructions*, or the *Handbook of Maintenance Instructions*.

One means of obtaining overvoltage protection is by the use of fuses in the power feeders. These are the same fuses which also serve as ground-fault protectors. The ampere rating of these fuses is such that nontransient overvoltages will cause sufficient overcurrent to open the fuses, before serious damage is done.

Where an overvoltage tripping relay protective mode is used, its general circuitry will usually be similar to that shown in figure 6-31. The average of all three phase voltages is translated through *T*1 and the rectifiers into an average d-c voltage which is applied to the coil of the trip relay When a high-voltage fault occurs, the trip

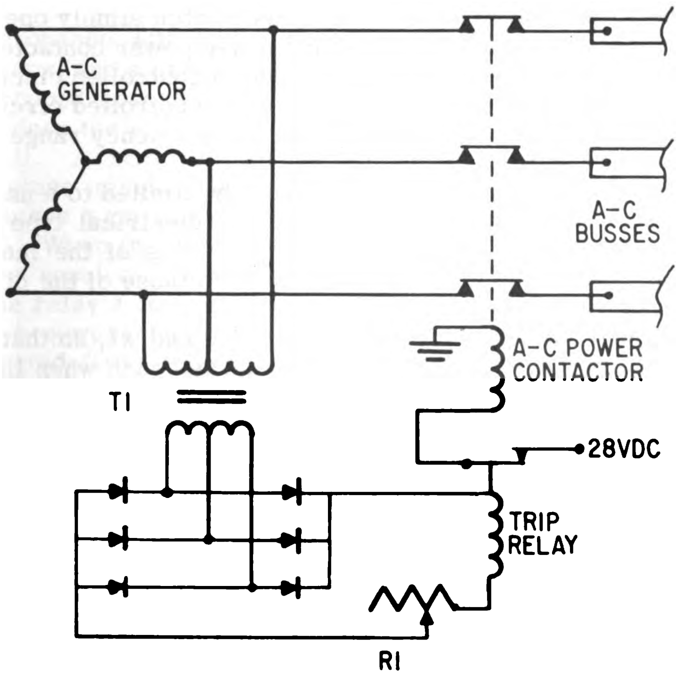


Figure 6-31.—Overvoltage protector circuit.

relay interrupts the d-c to the a-c power contactor, opening it, and disconnecting the a-c generator from its bus. Trip-voltage adjustment is made with $R1$.

Underfrequency Fault Protection

During certain phases of a-c generator operation, it is necessary to prevent the generator's output from being connected to its normal loads. One of the most common of these is during a low-frequency output condition, such as when the generator has been started but has not reached full speed. Another is when the generator has been shut down and slows below a safe output frequency. The generator may be connected or disconnected, as needed, through the use of any of a number of frequency-sensitive devices.

The simplest of these employs a speed switch which closes when the a-c generator's prime mover attains a safe speed (frequency). This speed switch simply opens or closes the circuit to the main a-c power contactor. In general, a mechanical speed-switch controlled circuit is not as sensitive as an electrically controlled circuit and so is used where the allowable frequency range is relatively wide.

Where frequency protection must be limited to a narrower range of generator speed, the electrical type is generally used. The operating principles of the most common electrical types are similar to those of the circuit shown in figure 6-32.

Line voltage is applied through $C1$ and $R1$, so that a certain portion of voltage appears across each when line frequency is correct. The voltage of $R1$ is applied through $C2$ to a parallel circuit consisting of $C3$ and $L1$ in one leg, and $C4$, $R2$, $RT1$, and the trip relay coil in the other leg. This parallel circuit is resonant at 400 cycles. Due to the characteristics of resonant parallel circuits, the impedance, and consequently the voltage drop, is maximum across points A and B (E_{AB}) when line frequency is 400 c.p.s. A portion of this voltage appears across the trip relay coil and holds its contacts closed. When line frequency decreases, however, more voltage is dropped across $C1$, so less voltage is impressed across the parallel circuit. In addition, the parallel circuit goes off

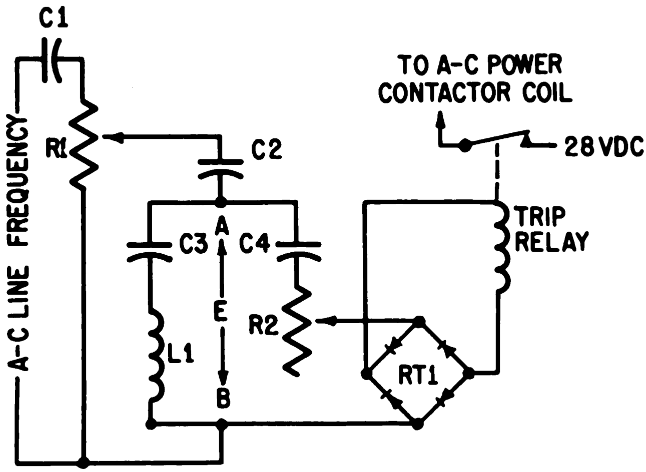


Figure 6-32.—Electrical underfrequency protector.

resonance with the change in frequency, its impedance drops, and a greater percentage of *R*1's output voltage is dropped across *C*2. Thus two effects have combined to reduce the voltage through *C*4, *R*2, *RT*1, and the trip relay coil. A still greater reduction in *R*2-*RT*1-trip relay voltage takes place because the decreasing frequency causes a greater percentage of E_{AB} to be dropped across *C*4. When the decrease of line frequency is great enough, the resultant decrease in trip relay coil voltage causes the relay's contacts to open. This in turn opens the main a-c power contactor, and the a-c generator is disconnected from the bus. Coarse adjustment of the trip frequency is made with *R*1, and fine adjustment is made with *R*2.

Phase Sequence Protection

Where a load is to be shared by two a-c generators, or where a given load may be supplied by more than one generator at different times, provisions must be made for indicating relative generator phase rotation prior to connecting an a-c generator to the bus. A common situation where such protection is needed is where an external a-c power unit, such as the NC-5, may be connected to an a-c system normally supplied by the aircraft a-c

generator. If the aircraft a-c generator is connected to the load with a positive phase rotation, it would not be allowable to use an NC-5 with a negative phase rotation. A phase sequence-sensitive relay designed to prevent this is shown in figure 6-33.

The unit consists of three filter networks; one sensitive only to a positive phase sequence, and the other two sensitive to a negative phase sequence. The output of two of the networks, marked POS. and NEG., operate their associated coils. When the a-c phase sequence at terminals A, B, and C is in the proper direction, the POS. coil is energized. If the phase sequence is reversed, the NEG. coil is energized. D-c voltage from the COM. terminal is connected either to the POS. SEQ. terminal, or NEG. SEQ. terminal, depending on which relay coil is energized. Thus, external power contactor *K*1 may be closed only when the external power source has the correct phase rotation. The third filter network is sensitive only to a negative phase rotation, and provides a voltage for a light or other warning device.

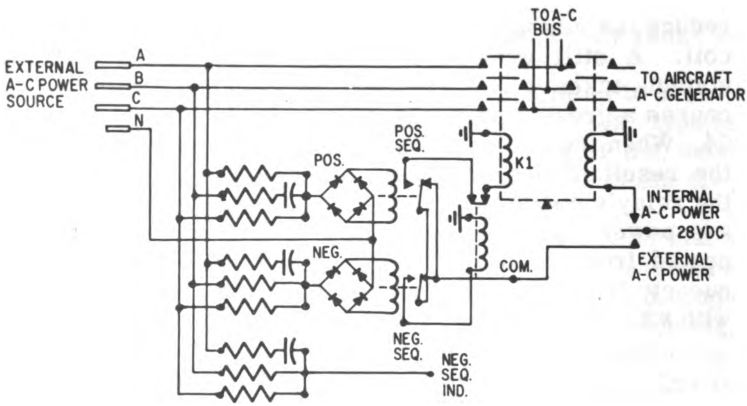


Figure 6-33.—Phase sequence relay.

QUIZ

1. The advantage of a rotating field-stationary armature machine over the rotating armature-stationary field type is that
   a. higher load currents can be utilized
   b. the need for sliprings is eliminated entirely
   c. heavier excitation currents can be carried
   d. less insulation is required due to lower coil voltages.

2. In an aircraft a-c generator
   a. a 5/6 pitch eliminates the third harmonic
   b. a 4/5 pitch reduces both the 4th and 5th harmonics
   c. the fractional pitch reduces armature reaction
   d. the fractional pitch improves voltage waveform.

3. When a salient-pole field is used in an a-c generator, the voltage waveform is improved by also using
   a. concentrated windings
   b. distributed field windings
   c. a 5/6 pitch to eliminate the third harmonic
   d. distributed armature windings.

4. A three-phase, three-wire generator gets extremely warm when operating with no load. The machine has just been reassembled. The trouble most likely is that the machine was mistakenly
   a. wye connected with a reversed phase
   b. delta connected with an open phase
   c. delta connected with a reversed phase
   d. wye connected with an open phase.

5. A-c generator armature reaction at no load
   a. distorts the main field flux
   b. is nonexistent
   c. opposes the main field flux
   d. aids the main field flux.

6. The factors affecting a-c generator regulation are
   a. armature resistance and power factor of the load
   b. resistance and reactance of the armature
   c. I^2R losses of the armature, plus windage and friction losses
   d. armature resistance, armature reactance, and armature reaction.

7. An a-c generator with a voltage regulator has a resistive load connected across its terminals which draws 10 amperes. The resistive load is replaced by an inductive load which draws 10 amperes. The
   a. terminal voltage will decrease
   b. excitation current will increase
   c. terminal voltage will increase
   d. excitation current will decrease.

8. An a-c generator with no voltage control has a full load e.m.f. of 120 volts, and a no-load e.m.f. of 145 volts. The percent of regulation is
   a. 8.3
   b. 17.2
   c. 20.8
   d. 83.0.

9. To parallel two three-phase a-c generators they must
   a. operate at the same speed
   b. have the same number of poles
   c. be in phase in the load circuit
   d. be carrying the same amount of load.

10. Two a-c generators are operating in parallel and supplying a lagging power factor load. The meter readings on the control panel are:

    Frequency: 400 cycles
    Volts: 120 volts
    No. 1 generator: 5 KVARS and 27 kw.
    No. 2 generator: 8 KVARS and 27 kw.

    To properly balance these loads
   a. increase the speed governor setting of No. 1
   b. decrease the excitation of No. 1
   c. increase speed governor setting of No. 1 and decrease speed governor setting of No. 2
   d. increase excitation of No. 1 and decrease excitation of No. 2.

11. Two a-c generators are properly paralleled and supplying power to a lagging power factor load. One means of shifting all of the load to No. 1 generator would be to
   a. decrease the speed governor setting and field current of No. 2
   b. decrease the speed governor setting of No. 1 and decrease excitation of No. 2
   c. decrease the speed governor setting of No. 1 and increase excitation of No. 2
   d. Increase the speed governor setting and excitation of No. 2.

12. Two a-c generators are to be synchronized by using three lamps as connected in figure 6-18. There is no apparent rotation of the lamps; lamps No. 1 and No. 3 are of equal brightness and lamp No. 2 is dark. The generators are
   a. synchronized, but 120 degrees apart
   b. prime-movers operating at the same speed
   c. synchronized, but are of improper phase rotation
   d. not synchronized, but operating at the same frequency.

13. When using the two-bright one-dark method of obtaining instantaneous polarity for paralleling a-c generators, improper phase sequence is indicated by
   a. all lamps flickering in sequence
   b. all lamps appearing dark
   c. all lamps flickering simultaneously
   d. two lamps dark and one bright.

14. The resistance of the exciter control relay used with some carbon pile voltage regulators to extend the control range, is placed in series with the
   a. exciter field when the current demand is slight
   b. a-c generator field under a full load, minimum speed condition
   c. exciter field under a no-load, high-speed condition
   d. a-c generator field under a no-load, high-speed condition.

15. In figure 6-19, *L*1 and *C*5 are tuned to 380 cycles. If capacitor *C*1 became shorted
   a. no current would flow in the control windings of the reactor bridge
   b. the frequency would be lower than normal
   c. the frequency would be higher than normal
   d. the frequency would hunt.

16. The automatic reactive load balancing system
   a. controls the magnitude and phase relation of the voltage supplied to the variable phase of a two-phase motor
   b. senses an unbalance of reactive loads between alternators operating in parallel by means of current transformers
   c. senses an unbalance of alternator terminal voltage by means of a delta transformer
   d. senses an unbalance in terminal voltages between two a-c generators operating in parallel.

17. Automatic real-load balancing
    a. is accomplished by a signal developed in the frequency discriminator circuit
    b. uses a current transformer sensing circuit to provide a signal to the voltage regulator circuits
    c. utilizes a combined wattmeter-variometer circuit to sense an unbalance in wattage between two a-c generators operating in parallel
    d. utilizes a current transformer sensing circuit to provide a signal to a reactor bridge network.

18. During the normal operation of a three-phase a-c generator, utilizing a static type voltage regulator, the exciter field current is
    a. a portion of the exciter a-c generator output and is controlled by the saturable reactors
    b. supplied by the a-c generator output through a rectifier and controlled by saturable reactors
    c. directly proportional to the a-c generator terminal voltage regardless of load
    d. supplied by the a-c generator output through a rectifier and controlled by varying the resistance of the field circuit.

19. In figure 6-26, during normal operation the current in the control coil is
    a. maximum when starting the inverter
    b. supplied from the rectified a.c.
    c. maximum at a high-speed, no-load condition
    d. minimum when starting the inverter.

20. In figure 6-27, if the inverter speeds up, the frequency across $R2$-$L1$-$C1$ goes above resonance. This will cause
    a. tube $V2$ to conduct for exactly one-half of each positive alternation of its plate voltage
    b. an increase in conduction through $V2$
    c. a decrease in conduction through $V2$
    d. tube $V2$ not to operate as a grid-controlled rectifier.

21. In the Leland inverter frequency regulator, the principle of operation is
    a. the charging and discharging of a capacitor through an RC network
    b. applying the average voltage of a capacitor to the grid of a tube, thus controlling the tubes, conduction
    c. that of a resonant RLC circuit tuned to the proper frequency
    d. that of impressing two unequal in-phase voltages across a capacitor.

22. A primary objective of a fault sensing system is to
    a. maintain controlled power to the vital circuits as long as possible
    b. protect the various load devices on the aircraft from excessive current
    c. maintain power to all essential circuits as long as the generator system will function
    d. protect the aircraft power system from all possible excessive current conditions.

23. A characteristic of fuse-mesh generator-feeder networks is that
    a. the generator is removed from the system whenever a ground fault occurs
    b. the pilot receives a positive indication at the time a fault circuit exists
    c. the fuses must be inspected after each flight to determine circuit condition
    d. each fuse is capable of conducting full-load current.

24. The overvoltage protective system
    a. is used to sense excessive generator terminal voltage due to an unbalanced load
    b. is not needed in parallel operation
    c. protects the distribution system from excessive voltage due to a malfunctioning voltage regulator
    d. protects load equipment from high voltage resulting from a high-speed condition.

25. The frequency sensitive relay and the underspeed switch
    a. must be reset manually after they have been tripped
    b. are used to protect the load equipment from a high frequency voltage supply
    c. permit paralleling of two a-c generators even though they have different frequencies
    d. are designed to protect the load from a low frequency voltage supply.

CHAPTER 7

SERVOMECHANISMS

In the operation of electrical and electronic equipment, it is often necessary to control a mechanical load that is remotely located from its source of control. Examples of this are the movement of flight control surfaces in automatic pilot operation and the movement of the pointer of a fuel capacity indicator. The mechanical load may require either high or low torque movement. For example, high torque is required for the movement of flight control surfaces, whereas low torque is required for the movement of a fuel quantity indicator pointer in a capacitance-type fuel quantity system.

It can be stated that a servomechanism is a device that positions an object with respect to a varied signal capable of supplying only small power. It operates to reduce to zero the difference that may exist between the actual and the desired position of the load.

COMPONENTS OF A SERVOMECHANISM SYSTEM

The essential components of a servomechanism system are the input controller and the output controller.

The input controller provides the means whereby the human controller controls the remotely located load. This may be achieved either mechanically or electrically. Electrical means are usually used. Synchro systems and bridge circuits are the most widely used methods of input control for servomechanism systems. If you feel that you

do not understand bridge circuits and synchro systems, it is suggested that you become familiar with them before studying this chapter. The Navy Training Course, *Basic Electricity,* NavPers 10086, gives extensive coverage to both.

The output controller of a servomechanism system is the component or components in which power development occurs. This power may be developed either by vacuum-tube amplifiers, magnetic amplifiers, or servomotors; in most applications a combination of these is used. The power is converted into a mechanical motion of the required torque and direction to produce the desired function. Figure 7-1 shows a simplified block diagram of a servomechanism system.

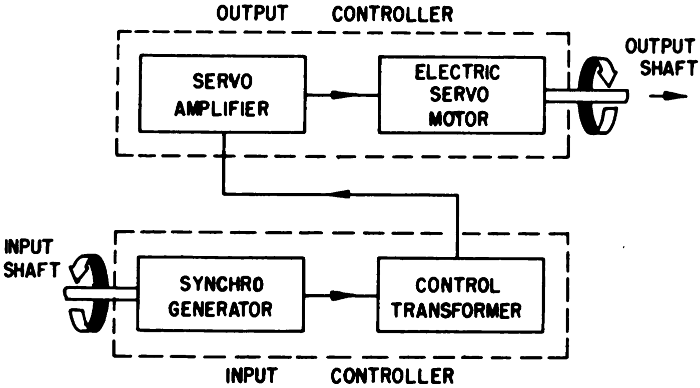


Figure 7-1.—Simplified block diagram of a servomechanism.

It is frequently necessary to control the position of a device in accordance with some function of a signal supplied by a controlling instrument. If the power required to operate the device is larger as compared to the power available from the controlling instrument, power amplifying means must be provided. When the amplification of the input controlling signals is carried out by a machine or automatic device rather than by a human operator, the complete system is known as an automatic control system.

Automatic control systems can be divided into two types, depending upon the source of the signals that actuate the output controller. If the signals supplied to the output

controller are determined not only by the controlling instrument but also by the position of the device being controlled, the system is known as a closed-loop control system. This system is the one most frequently used since it is seldom possible to find a power controlled mechanism in which the loop is not closed either mechanically, or through a human link. If the signals supplied to the output controller are not a function of the position of the device being controlled, the system is known as an open-loop control system. Figure 7-1 is an open-loop control system; however, if a signal from the output shaft was generated and routed back to the input, then this would be a closed-loop system.

SERVOMECHANISM TERMS

The term servomechanism refers to a large variety of power amplifying devices.

The following terms have been applied to servomechanisms. The quantities defined are well established and, although they have not been standardized, are understood by those active in the field.

INPUT - The input is the controlling quantity. It may be the displacement of a shaft, a voltage or current, a temperature level, and so forth.

OUTPUT - The servo output is the position or state of the controlled quantity. It may be any of the quantities listed in the definition of the input.

ERROR - The servo error is the difference between the servomechanism input and the output.

ERROR DETECTOR - The error detector is the device which compares the input with servomechanism output.

SERVO CONTROLLER - The servo controller is the device in which the input is the error and the output controls the servomotor.

SERVOMOTOR - The servomotor is the prime mover of the servomechanism. It is actuated by the servo controller and controls the servo load or output.

SERVO LOAD - The servo load is the quantity upon which the servomotor operates.

DATA TRANSMISSION SYSTEMS

In some servomechanisms the data transmission system may consist solely of an error detector (control

transformer). In many servo systems, both the physical position of the servo output and the origin of the signals comprising the servo input may be remote from one another and from the servo controller. The function of the data-transmission system is to transmit a signal from the input signal generator to the control transformer. This signal is combined with the servo output in the error detector (control transformer) which determines the magnitude and direction of error. This signal is then applied to the servo controller.

The error detector is the component of the data-transmission system that is used for comparing the input and output functions. The error may be resistive (potentiometer), capacitive, or the output from one of several types of transforming devices.

A commonly used transformer error detector is the synchro. The synchro has been developed to the point that it is characterized by relatively high accuracy, low noise level, reasonably small driving torques, and excellent life. Some of the disadvantages of synchros are: (1) the large size necessary to maintain high accuracy; (2) the high power consumed; and (3) the fact that the output supplied to the servo controller is always an alternating voltage modulated by the servo error angle and must be demodulated in either the servo controller or the servomotor.

The synchro data-transmission system is comprised of a synchro generator, a synchro receiver, and in some cases a differential generator. (Refer to *Basic Electricity*, NavPers 10086, for the theory of operation and function of a differential generator.) The synchro generator transforms the motion of its shaft into electrical signals. These signals are transmitted to the synchro receiver which is the error detector.

The stator of the generator consists of 3 coils spaced 120 electrical degrees apart. The voltage induced into the stator windings is a function of the position of the generator rotor. These voltages are applied to the 3 similar stator windings of the synchro receiver or a control transformer. The voltage induced in the rotor of the synchro receiver depends upon the relative position of the generator rotor with respect to the direction of the stator flux. The variation of the synchro-receiver output voltage as a

function of the rotor position relative to an assumed stator flux direction is shown in figure 7-2. While there are two positions of the rotor, 180 degrees apart, where the output voltage is zero, only one corresponds to a stable operating position of the servo.

Another type of error detecting element commonly used in the data-transmission system is the potentiometer. Potentiometers are generally used only where the input and the output of a servomechanism have limited motion. They are characterized by high accuracy, small size, and the fact that a d-c or a-c voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage out of the potentiometer changes in separate steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high driving torque required.

Figure 7-3 shows a typical servo system with a potentiometer data-transmission system.

SERVO AMPLIFIER

The servo amplifier supplies the required amplification of the error signal. In most data-transmission systems, the strength of the error signal generated is in millivolts. Besides amplifying the error signal, the amplifier also changes the servo signal into suitable form for controlling the servomotor.

A servo amplifier is usually divided into three sections—the preamplifier, the sense detector, and the power amplifying section. Figure 7-4 shows a block diagram of a servo amplifier.

PREAMPLIFIER.—The preamplifier section is a voltage amplifier. Its function is to increase the amplitude of the input signal error voltage without changing its electrical characteristics. In most preamplifier stages, the amplifier operates in class A. Most preamplifiers for a servomechanism system need more than a single stage of voltage amplification. To obtain greater gain, several stages are utilized to produce a single output. This arrangement is called a cascade amplifier.

SENSE DETECTOR.—The sense detector (second section in the block diagram of fig. 7-4) detects the phase

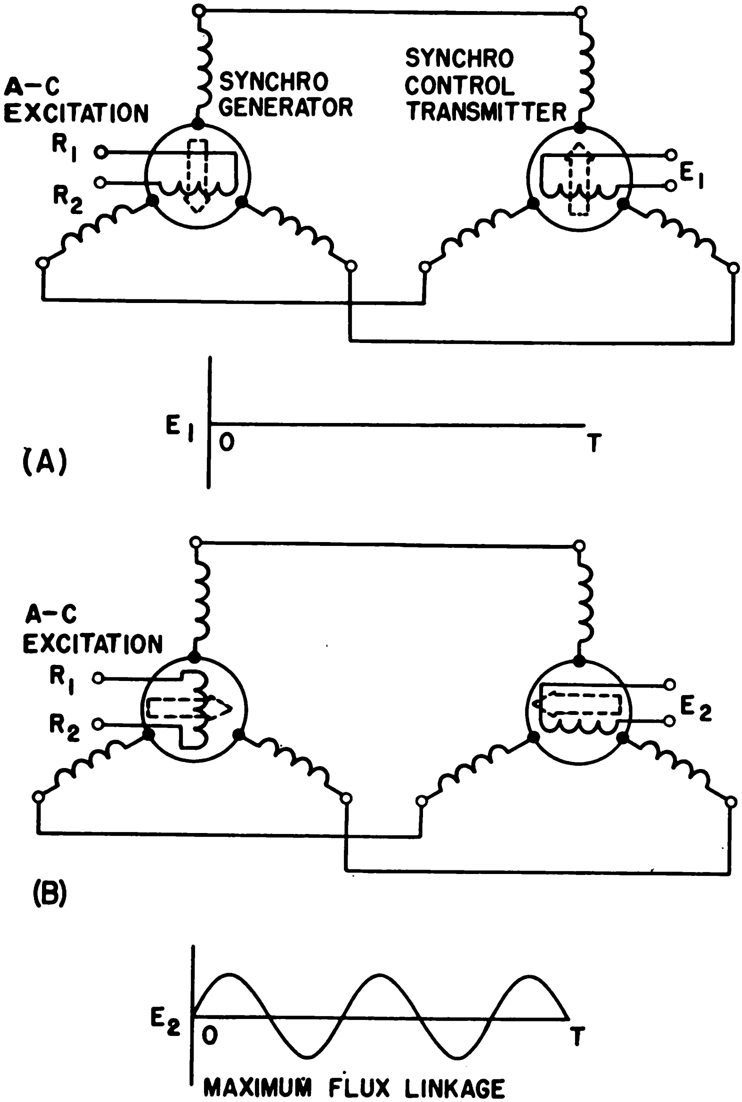
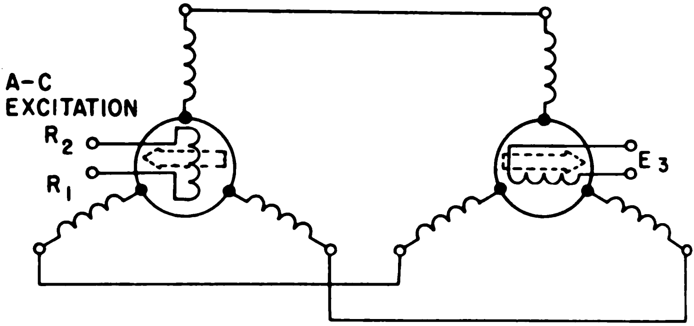


Figure 7-2.—Induced voltage in synchro control transformer rotor.



(C)

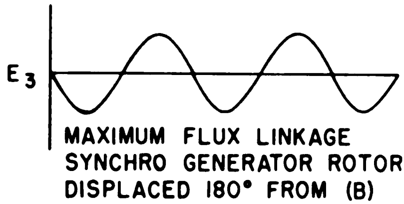


Figure 7-2.—Induced voltage in synchro control transformer rotor.—Continued

polarity of the amplified error voltage in reference to a fixed voltage. The sense detector ultimately controls the direction in which the servomotor rotates. It does this by controlling either the timing or direction of the power amplifier output.

A typical diode phase discriminator, which is a sense detector, is shown in figure 7-5. As illustrated, an a-c excitation voltage serves as the reference voltage to the discriminator. This voltage must come from the source supply that will create the voltage to be compared to the reference. The plates of the two diodes are supplied with this reference voltage in such a manner that they will be in phase. Assuming that there is no error signal from *T*2 into the plates of the diodes at the time the plates are on a positive half cycle, the two diodes will conduct equally. The voltages produced across *R*1 and *R*2 are at equal potential with respect to ground. The a-c component is removed by capacitors *C*1 and *C*2. The output is zero as long as no signal is introduced by *T*2.

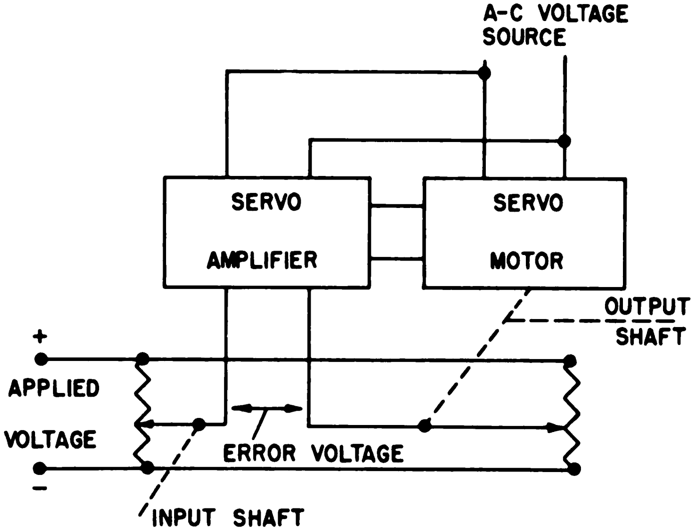


Figure 7-3.—A potentiometer data-transmission system.

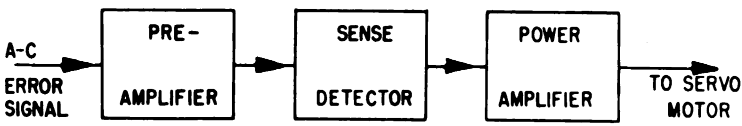


Figure 7-4.—Block diagram of servo amplifier.

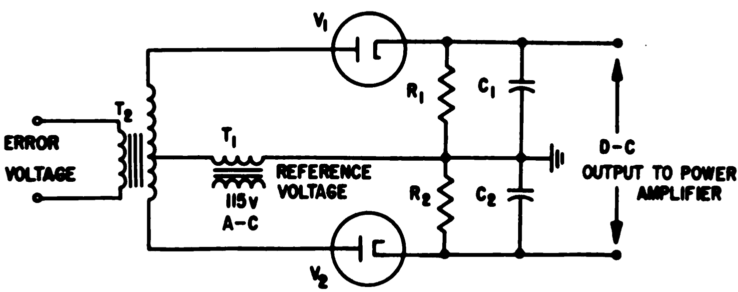


Figure 7-5.—Phase sensitive rectifier using diodes.

For a further understanding of the circuit, assume that a control transformer is controlling the circuit and is manually turned to a position to produce an a-c voltage of a definite phase relationship to the reference voltage and of an amplitude determined by the amount of rotor change. If the phase relationships of the two voltages are such that the plate of *V*1 has a positive half cycle of error signal at the same instant that the reference voltage on the plates is on its positive half cycle, *V*1 will conduct more than *V*2. At this same instant, the plate of *V*2 will have a negative half cycle of the error signal, which will reduce its conduction. The cathode of *V*1 is now positive in respect to the cathode of *V*2, due to the charges on *C*1 and *C*2. The change in amplitude in this direction will actuate a control circuit which will move the output shaft in the proper direction. The correction speed of the output shaft will, through a feedback device, cause the error voltage to drop to zero, at which time the output voltage will return to its static level, stopping the controlling action.

If the rotor of the control transformer were turned in the opposite direction, the phase of the voltage applied to the primary of *T*2 would be changed by 180 degrees. Simultaneously, the plate of *V*1 would receive a negative half cycle of error voltage from the secondary of *T*2, while, at the same instant, the two plates would be on a positive half cycle of the reference voltage. Thus, the conduction of *V*1 will be reduced and the conduction of *V*2 will increase above its static level. The d-c output will change so that the cathode of *V*2 will be positive in respect to the cathode of *V*1. This new error signal will thus cause the d-c voltage output to be in a direction opposite to that previously given. This causes the output shaft to move in the opposite direction.

A triode phase discriminator is widely used in servo amplifiers which the Aviation Electrician will maintain. Figure 7-6 shows a typical triode phase discriminator circuit.

In this circuit, as in the previous one, the plates of the tubes are supplied with the a-c reference voltage in such a manner that they are in phase. For purposes of explanation, assume that no error signal is present at *T*2. When the plates of *V*1 and *V*2 are positive, the two tubes will

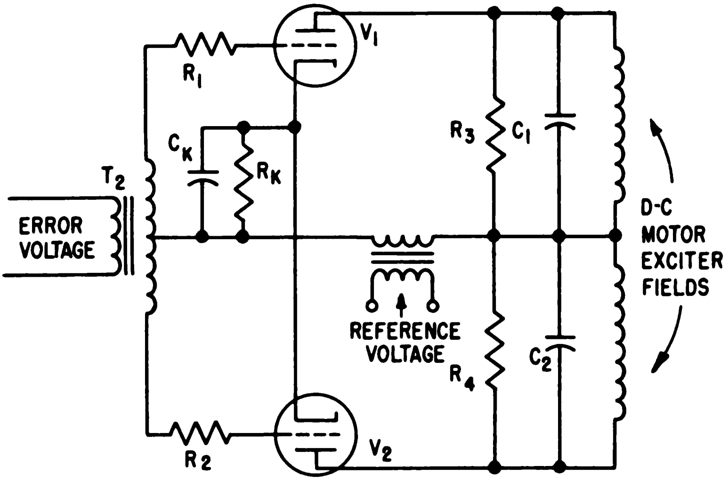


Figure 7-6.—Triode phase discriminator circuit.

conduct equally. The plate current that flows will set up fields in the d-c motor exciter windings that are equal and opposite; therefore, the fields cancel and produce no output torque. When the plate voltages are on a negative half cycle, *C*1 and *C*2 maintain a constant d-c current through the windings.

If an error signal is introduced into the primary of *T*2 of such a phase relationship that the grid of *V*1 will be positive at the same instant that the plate of *V*1 is positive, the following conditions will exist:

1. On this half cycle the conduction of *V*1 will be increased above its static value.

2. The heavier plate current will cause a stronger field to be created in the upper exciter windings.

3. At this same instant, since the grid of *V*2 is on a negative half cycle, its average conduction will be reduced to a level below that of its static value, producing a weaker field in the lower exciter winding.

4. Since the magnetic fields produced in the exciter windings are no longer of equal amplitudes, they can no longer cancel each other, and mechanical torque is developed by the d-c motor.

5. The motor rotation will cause the proper mechanical actions necessary to reduce the amplitude of the error to zero.

6. As the error signal is reduced to zero, the current conduction through $V1$ and $V2$ will again be balanced, the exciter fields will be equal, and mechanical action will be stopped. (Resistors $R1$ and $R2$ prevent excessive grid current when the error signal is large.)

In many applications the servomotor will be a two-phase a-c motor. The triode phase discriminator circuit just described can also control the a-c servomotor. This is done by allowing the triode phase discriminator d-c voltage to control the control winding of a magnetic amplifier. Figure 7-7 shows a typical triode phase discriminator circuit in which a magnetic amplifier is used to control a two-phase a-c servomotor. (Magnetic amplifiers are discussed in chapter 5 of this training course.)

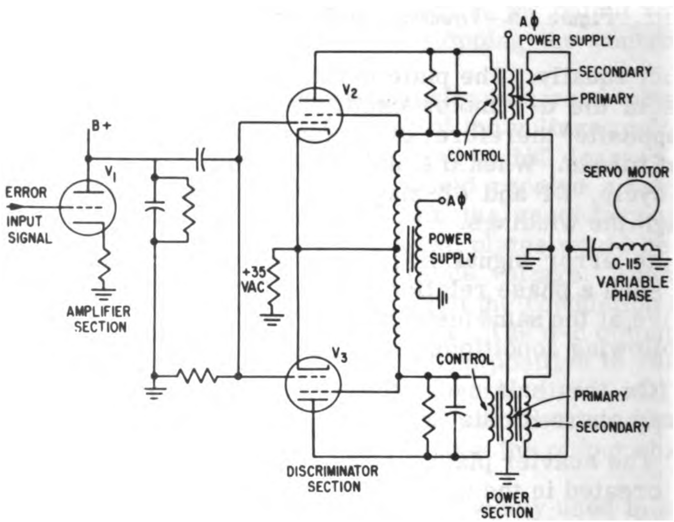


Figure 7-7.—Servo amplifier using triode phase discriminator to control a magnetic amplifier.

Referring to figure 7-7, the plates of the two discriminator tubes $V2$ and $V3$ are connected to opposite ends of a transformer, while their cathodes are connected at a common midpoint of the transformer. This results in a 180-degree phase difference between the plates of $V2$ and

V3. The cathode of each discriminator tube is fix biased at plus 35 volts d. c. The tubes are therefore held at cutoff when no signal is applied to their grids.

An a-c plate voltage is applied to both discriminator tubes. Each tube conducts only when its plate is positive with respect to its cathode. Since the plate voltages are 180 degrees out of phase, the tubes conduct alternately. When a small positive signal is applied to a tube the grid is brought above cutoff and the tube conducts. This occurs whenever the sensing detector sends an error signal to the amplifier. (The same signal appears at the grids of both discriminator tubes.) The plate and grid voltages are phased so that the grid voltage is either in phase or 180 degrees out of phase with the plate voltage for a particular tube at a particular time. The output of each tube is filtered and goes to the d-c control winding of a magnetic amplifier, which supplies power amplification of the correct magnitude and phase.

The magnetic amplifier consists of two sets of three windings; each set is wrapped around a separate core. The magnetic amplifier may be considered to be two transformers. Each has a primary winding, a secondary winding, and a control winding. The control winding controls the flux density in the core and the voltage induced in the secondary. The secondary windings of the two transformer sections of the magnetic amplifier are connected in series-opposing. Since the two transformer sections are electrically identical, equal voltages are induced in the two secondary windings when there is no signal to the control windings. However, the primary and secondary windings are wound so that the voltages induced in the two secondaries buck each other. Therefore, there is no output from the magnetic amplifier.

When a signal is passed to the amplifier, the originally equal output signals from the magnetic amplifier section now become unequal. The difference between both output signals is proportional to the amplifier input signal. Since the output signals from the two transformer sections buck each other, the series combination of these two signals is a signal that is equal in magnitude to the difference between the signals and is of the same phase as the larger signal. The output signal from the magnetic amplifier is then passed to the variable phase of the servomotor, thus

resulting in clockwise or counterclockwise rotation of the servomotor shaft.

SERVOMOTORS

Servomechanisms may be classified according to motive characteristics. Three types of motor drives are used extensively in positioning systems. They are the d-c motor, the a-c motor, and the hydraulic motor.

The d-c motor is a high torque device and is widely used in servomechanisms where smooth control of heavy loads is desired. The d-c servomotor is a specialized form of the standard d-c motor in that it is designed to provide nearly linear changes in speed with proportional changes in armature current. This feature permits the d-c servomotor to change its direction and speed of rotation smoothly, and with minimum mechanical stress on the controlled mechanism.

The two types of d-c motors used in servomechanisms are the split-field d-c motor and the shunt-field d-c motor. The split-field d-c motor is used when the mechanical load is light to moderate; when larger power requirements are necessary, the shunt-field d-c motor is used.

The a-c motor is essentially a constant speed device. This characteristic makes it impractical for use as a servomotor in a number of applications. Nevertheless, a-c servomotors are used extensively in many systems where a rapid, accurate, and low cost servomechanism is required. Moreover, since a-c devices and systems are generally far more flexible and trouble free than their d-c counterparts, considerable research has made it possible for a-c servomotors to gain increasing favor with servo system designers. A few advantages of the a-c servomotor are: (1) no commutator and brush maintenance; (2) a-c amplifiers are not subject to the drift (development of an output signal with no input signal) encountered in d-c amplifiers; and (3) it is preferred where space is limited, since the commutator of a small d-c servomotor occupies a large part of the motor volume.

The two-phase induction motor is the most widely used a-c motor for servomechanism systems. The stator of the motor consists of two similar windings which are positioned at right angles to each other. The rotor may

be wound with short-circuited turns of wire or may be a squirrel cage rotor. The squirrel cage is most common and is made up of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends. Figure 7-8 is a simplified cross-sectional view and a schematic diagram of a two-phase induction motor.

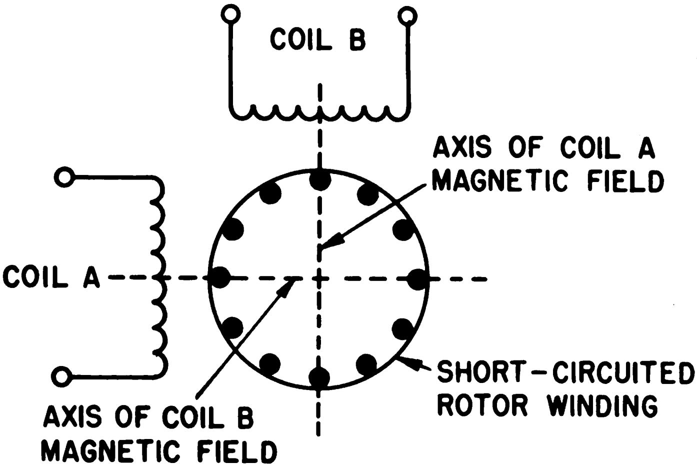


Figure 7-8.—Simplified cross-sectional view of a two-phase induction motor.

Referring to figure 7-8, if the voltages applied to coils *A* and *B* are 90 degrees out of phase, the currents that flow will also be displaced by 90 degrees. Since the magnetic fields generated in the coils will be in phase with their respective currents, the magnetic fields will also be displaced 90 degrees with respect to each other. The two magnetic fields will add together at every instant during their cycle to produce one resultant field which will rotate one revolution for each cycle of the a.c. As the magnetic field rotates, it cuts through the short-circuited conductors on the armature and induces a voltage in them. The induced voltage will cause a current to flow in these conductors. Whenever current-carrying conductors exist in a magnetic field, motor action results and a turning force is exerted on the conductors in the same direction as the rotating magnetic field. Therefore the armature of the motor starts rotating.

In order to reverse the direction of rotation of the motor, the current flowing in either one of the coils must be reversed. This will reverse the direction of rotation of the magnetic field and the rotor will turn in the opposite direction. The torque of the motor can be varied by varying the strength of one of the magnetic fields.

The hydraulic motor servomechanism is a rugged power amplifying device, operating on the hydromechanical principle. This type of system, which was in use before the development of electrical servomechanisms, supplies a very large power output with the advantage of a relatively small physical size. The operation of the hydraulic system is rapid and smooth. Because of its rugged construction, it is used extensively where heavy loads must be positioned.

Due to the limited use of the hydraulic drive in aviation servomechanism systems, no further discussion is considered necessary.

FOLLOWUP SYSTEMS

The followup system in servomechanism systems is similar to a degenerative feedback circuit in electronic circuits; that is, it tends to cancel the original signal applied to the amplifier.

In a servomechanism system, an error signal is developed by an input controller. (See fig. 7-1.) This signal is amplified and then sent to the servomotor. The servomotor operates (moves the load) until the input error signal returns to zero. There are two ways of returning the input error signal to zero: (1) by manually moving the input shaft in such a direction that the error signal voltage developed by the input controller is zero, and (2) moving it automatically by the the followup method.

The followup system is one that controls the amount of movement or displacement of a mechanical load. This is done by using potentiometers or synchro circuits. Figure 7-9 shows a simplified servomechanism system employing a synchro followup circuit.

The followup system in figure 7-9 consists of a synchro whose rotor is mechanically connected to the output shaft of the servomotor. The mechanical connection may be direct or it may be made through reduction gears. If the

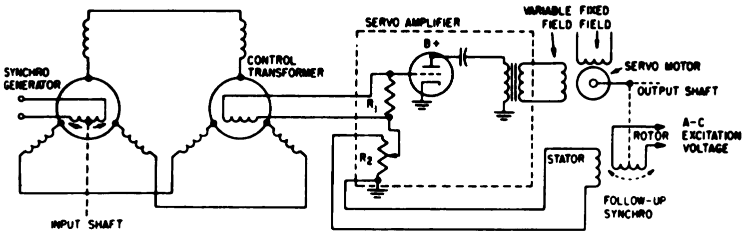


Figure 7-9.—Servomechanism system using a followup synchro.

servomotor is allowed to rotate a full 360 degrees, the followup synchro rotor will be connected to the servomotor output shaft by a stepdown gear, allowing the synchro rotor to turn only a few degrees as the servomotor turns many revolutions. The reason for this type of synchro rotor drive is to assure that the synchro rotor operates from one null position. In the study of control transformers and synchros, it has been shown that in order to produce a signal (voltage) of one particular phase, the synchro rotor must operate from one null position. If the synchro rotor were allowed to rotate 360 degrees, the output signal (voltage) of the synchro stator would change phase relationship twice during every 360-degree rotation of the synchro rotor.

The followup synchro rotor is positioned so that its magnetic field produces a minimum voltage in the stator when the servomotor is at rest in its normal position. This position is known as the null position.

Any signal that is developed by the input controller will cause the servomotor to rotate. This rotation may be clockwise or counterclockwise, depending on the phase relationship of the input signal. As the servomotor rotates, it will cause the output shaft and the followup synchro rotor to turn. The turning of the followup synchro will cause a voltage to be developed in the synchro stator. The phase relationship of the followup stator's voltage will always be 180 degrees out of phase with the output voltage of the input controller. The magnitude of the followup voltage will be directly proportional to the angular movement of the followup synchro rotor from its null position. The two voltages, the input and the followup,

will appear across resistors *R*1 and *R*2, respectively. (See fig. 7-9.)

The two resistors *R*1 and *R*2 are connected in series with each other and in series with the grid and cathode of the preamplifier. The grid voltage of the preamplifier will be the resultant of the voltages developed across *R*1 and *R*2.

Initially, the voltage across *R*1 causes the servomotor to operate. As the followup rotor moves from null, the followup voltage appears across *R*2, subtracting from the voltage developed across *R*1. When the servomotor has moved the load and the followup rotor far enough to cause the followup voltage to be equal in magnitude to the voltage of *R*1, the servomotor will stop, as the voltage on the grid becomes zero. The servomotor can be made to rotate further in the same direction by displacing the input shaft further. It will rotate until the followup signal again has equaled the voltage of *R*1.

If the input shaft were turned in the opposite direction, then the followup voltage would be larger than the input voltage of *R*1. Since the followup voltage is 180 degrees out of phase with the input voltage of *R*1, the signal (voltage) applied to the preamplifier grid will be that of the followup. This voltage causes the servomotor to rotate in the opposite direction. The servomotor will rotate until the input and the followup voltages are again equal.

It can be seen that the followup system of a servomechanism system prevents overcontrol of the load. Without followup it would be impossible to stop a servomotor at a selected position.

ANTIHUNT DEVICES

If the input shaft of a servomechanism is suddenly turned to a new position, the output shaft is often found to oscillate several times about its new position before coming to rest. This is due to the inertia and friction of the output shaft. Oscillatory motion of a servomechanism is often referred to as hunting.

Special devices or networks, which permit the gain of the amplifier to be increased without sustained oscillations occurring, are often included in servomechanisms.

An obvious method of stabilizing a servo system is to increase the mechanical friction at the output shaft. By

sufficiently increasing this friction, not only can oscillations be prevented but also any desired degree of damping can be obtained. Due to various disadvantages associated with this method of damping, it is seldom used. One major disadvantage is that much power is wasted, since the servomotor must produce many times the amount of power required to turn the load. Most of this power output is converted into heat by damping friction.

Another disadvantage is that velocity errors are increased by the friction; that is, the friction increases the angle by which the output shaft lags the input shaft when both are turning at constant speed. The damping friction causes a torque at the output shaft, and an error is required to make the servomotor supply this torque.

The most efficient method of antihunt damping is electrical. This method eliminates the disadvantages of the mechanical antihunt device.

Electrical Damping of A-C Servomotors

The most common electrical method of damping the a-c servomotor is by use of the rate generator.

A rate generator consists of two separate field coils and a squirrel cage rotor. Its construction is very similar to that of a two-phase induction motor. However, where the induction motor utilized electrical energy in its field coils to produce rotor movement, the rate generator utilized rotor movement to produce electrical energy in one of its field coils. Figure 7-10 shows a simplified schematic of a rate generator.

The rotor of the rate generator is connected on the same shaft as the rotor of the servomotor. Therefore, the speed of the rotor of the rate generator is directly proportional to the speed of the servomotor rotor (1:1). The direction of rotation of the rotor of the rate generator is determined by the phase relationship of the input signal causing the servomotor rotor to rotate.

A-c voltage is used to excite the fixed field of the rate generator. In aircraft installations this excitation voltage is usually 16 volts; its frequency is 400 cycles. The fixed field excitation voltage produces a magnetic field about the rotor of the rate generator.

If the rotor of the rate generator is rotating, the imbedded conductors of the rotor will cut the magnetic field

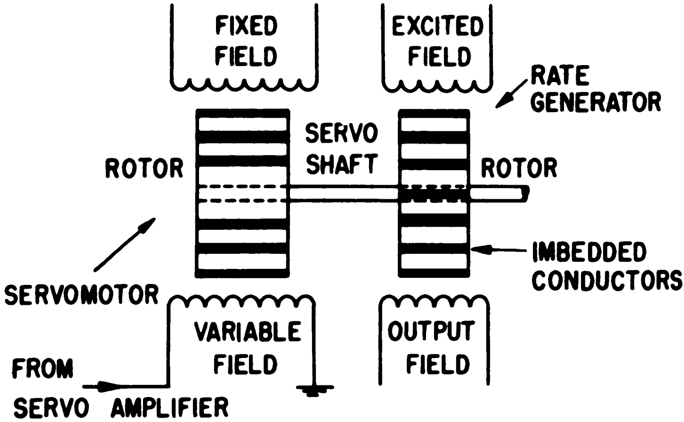


Figure 7-10.—Rate generator, simplified.

produced by the fixed field. This cutting of the magnetic field causes current to flow in the conductors of the rotor. Since these current-carrying conductors also pass by the unexcited field, they will produce a voltage in the winding of the variable field. The voltage induced into the variable field will have a magnitude directly proportional to the speed of the servomotor. The phase relationship of the voltage of the variable field will be determined by the direction of rotation of the servomotor rotor. This is illustrated in figure 7-11.

The output voltage of the rate generator's variable field is phased so that it always opposes the variable field input voltage of the servomotor. Since the speed of the servomotor rotor determines the magnitude of the output voltage of the rate generator, it can be seen that the rate generator output voltage can never completely cancel the servomotor's variable field voltage. However, it will furnish a damping effect by regulating the voltage of the input signal.

In most servomechanism installations that employ the rate generator as a damping device, the output of the rate generator is connected in series with the servo's followup output, as shown in figure 7-12.

The two voltages (rate generator and followup) may be in phase with each other, or 180 degrees out of phase. If the servomotor is being driven by an error signal, the

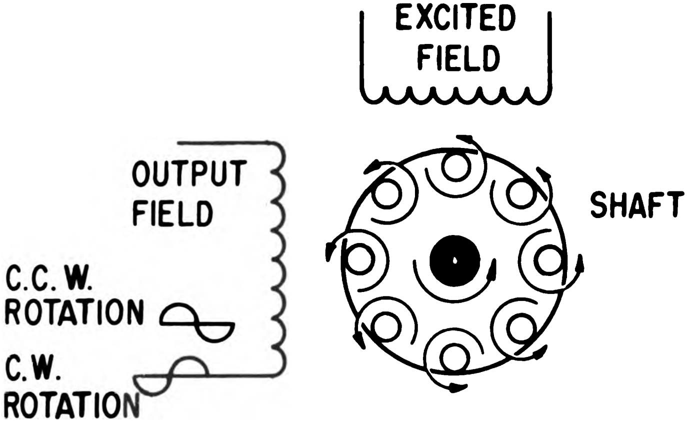


Figure 7-11.—Phase relationship.

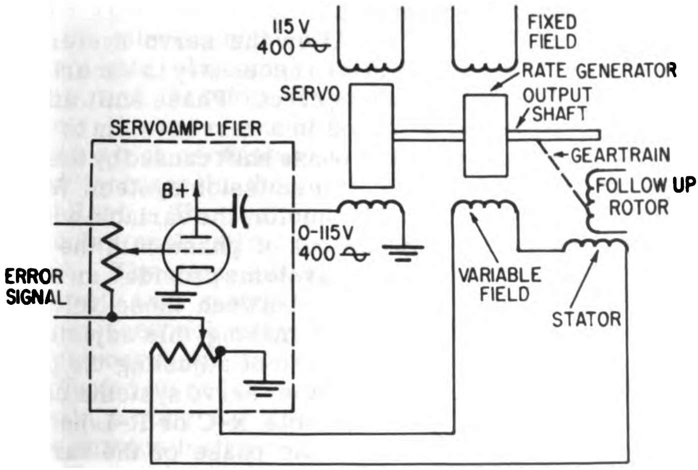


Figure 7-12.—Schematic of a closed-loop servo system.

rate generator voltage and the followup voltage will be in phase with each other and out of phase with the error signal, thus controlling the damping and the total movement of the servomotor.

If the followup voltage is driving the servomotor, the rate generator voltage will be out of phase with the followup voltage. This regulates the servomotor speed on its return to null position and prevents "overshooting."

Servomechanism Adjustments

It is important that you know how to make the proper adjustments to servomechanisms in order to obtain proper performance. Adjustments must be made when new equipment is installed, when components such as control transformers, differential synchros, servo amplifiers, tubes, or other parts of the servo system are replaced, and during normal service as a result of variations in the system due to normal usage. These adjustments will provide changes in gain, phase, and balance of the servo amplifier, and also the alinement or zeroing of the synchros and followups of the system.

The zeroing of synchros has been discussed in general in *Basic Electricity,* NavPers 10086, and will not be discussed in this chapter. Instructions for a specific type of equipment will be found in the *Handbook of Service Instructions* for that equipment.

PHASE ADJUSTMENT.—After the servo system has been zeroed or alined, it is then necessary to ascertain if the phase relationships are correct. Phase shift adjustments are frequently provided in a servo system to compensate for any undesirable phase shift caused by the amplifier or the synchro data-transmission system. When a system uses a two-phase servomotor, the variable winding voltage must be 90 degrees out of phase with the fixed voltage winding. Many servo systems provide a means of adjusting the phase difference between these voltages. There are various methods of making this adjustment. Some equipments provide a means of adjusting the phase of the fixed voltage winding. Other servo systems use an amplifier that contains a variable R-C or R-L network which, when adjusted, varies the phase of the variable voltage winding.

An improper phase difference may be detected with an oscilloscope. This procedure is explained in chapter 14 of this training course, under the heading "Phase Comparison."

Phase adjustments are generally made with the system at rest (no input signal). In order to provide sufficient output from the control amplifier for comparison with the input to the fixed winding, it is desirable to physically hold the servomotor away from its correspondence

position. The phase adjustment is then made so as to provide a 90-degree phase displacement.

When a new system is installed or components replaced, it is necessary to check connections for proper polarity relationships. Unless the fixed and controlled voltages have the proper polarity relationships, the servo will not have stability and the motor will run uncontrolled. Likewise, if a rate generator is used in the servo system, the output of the generator must have a polarity that will increase the system's stability rather than decrease it.

EFFECT AND ADJUSTMENT OF CONTROLLER GAIN.—The overall gain of the system has a most important effect on servomechanism response characteristics, and is one of the more easily adjustable parameters in electronic servo controllers. Increasing the system gain reduces the system velocity errors and those static errors resulting from restraining torques on the servo load or misalinement in the system. An increase in system gain also increases the system's natural frequency; and therefore its speed of response to transient inputs. However, excessive gain always decreases the rate at which oscillatory transients disappear, and continued increase in the system gain eventually produces instability. The optimum gain setting depends on the particular application for which the servo system is intended. The gain should always be as high as is commensurate with system damping.

When feedback networks are used, the relative gains of these networks and the amplifier's forward gain must be adjusted in order to obtain optimum performance. If the gain setting for these two adjustments are not given in the service instructions, they may be obtained experimentally by gradually adjusting first one and then the other.

Since the gain of the servo will be affected by the phase of the various voltages, it is desirable to check the phase adjustments before making the gain adjustments. When small servomotors are used, it is possible to measure the dynamic performance by checking the number of overshoots. This may be done by causing the rotation to cease, then manually rotating the servomotor a certain number of degrees from correspondence, and then allowing it to snap back to its correspondence position. The

number of overshoots for a particular amount of servo displacement must be determined experimentally from equipment that is functioning properly. This may be used as a comparison guide between the same types of equipment that are functioning properly. As a rule in aviation equipment, due to weight limitations, the servomotor has little torque in excess of that required of it. Because of this, whenever any additional load is added to the motor, the system is apt to become sluggish or intermittent.

Oftentimes the servo amplifier is thought to be the cause of the above action when in reality it is due to an increase in load. This increase may be caused by excessive mechanical friction due to worn gear trains or defective bearings, and may frequently be detected by manually rotating the servomotor with power removed. The amount of effort required to rotate the system that is not operating properly is compared with that required to rotate a system that is operating properly.

BALANCE ADJUSTMENT.—Frequently, servo amplifiers contain a balance adjustment to overcome any electrical unbalance that may occur in the amplifier. This unbalance is primarily caused by the unequal conduction of tubes. The adjustment is generally provided by connecting a potentiometer in the cathode circuits of the output tubes. This potentiometer is sometimes place in the cathodes of the driver stage instead of the output stage. As the potentiometer is changed, the cathode bias will increase on one tube and decrease on the other, depending upon the direction of movement of the potentiometer arm. Thus, by proper positioning of the potentiometer, the tubes can be made to draw equal current.

When this adjustment is made, it is necessary to short out the input to the servo amplifier. With zero input to the amplifier, the balancing adjustment is rotated to the null or minimum voltage output from the servo amplifier. This indication is taken from a meter that is connected across the output winding or from a test jack.

APPLICATIONS OF TYPICAL SERVOMECHANISMS

The remainder of this chapter will be devoted to an explanation of the theory and operation of two different

servomechanisms that are typical of airborne servo systems. Automatic pilot application will not be discussed in this chapter, but will be fully discussed in chapter 10 in connection with automatic flight control systems. The first explanation will deal with servo system used to control a searchlight, and the second will explain the servomechanisms used in capacitance fuel quantity systems.

Aircraft Searchlight Servo System

Aircraft searchlights were discussed in chapter 4 of *AE 3 & 2,* NavPers 10348. A further discussion in how the positioning of the searchlight is controlled will be given in this chapter. Figure 7-13 shows a diagram of a typical aircraft searchlight system.

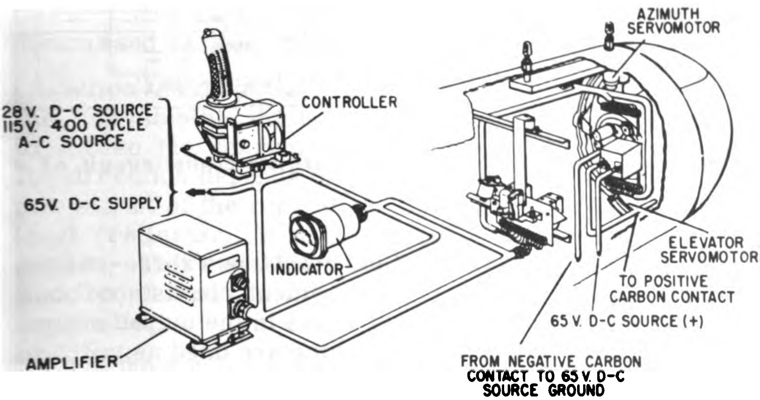


Figure 7-13.—Aircraft searchlight control system.

The searchlight is controlled by a controller which contains two synchros; one is used for azimuth control and the other for elevator control. The two synchro outputs are amplified in the searchlight amplifier. This amplifier has two identical sections, one for azimuth signal amplification and power output, and the other for elevator signal amplification and power output.

The outputs of the amplifier are sent to two servomotors located in the searchlight unit. One motor is for azimuth control and the other is for elevation control.

The position of the searchlight reflector is transmitted to an indicator which indicates to the operator the position of the reflector.

Only the azimuth control circuit will be discussed since its operation is identical to the elevation control circuit. Figure 7-14 shows a schematic diagram of an azimuth control circuit.

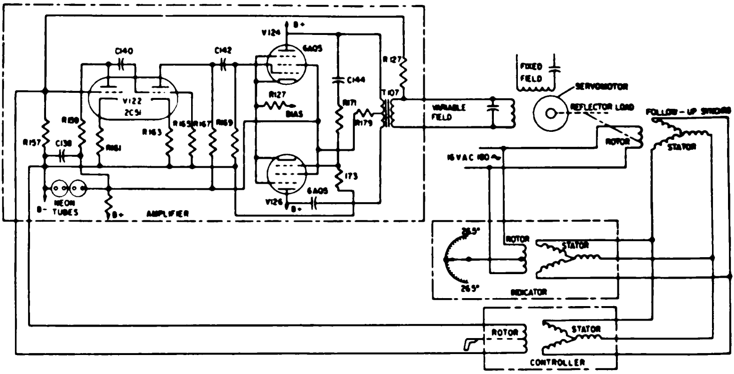


Figure 7-14.—Schematic diagram of the azimuth control circuit of a searchlight.

The amplifier shown in figure 7-14 is a three-stage, 180-cycle type. Its tube complement consists of one 2C51 and two 6AQ5 beam-power tubes in the output stage. There are also two neon tubes which are used as voltage regulators.

The first stage of the amplifier provides voltage amplification. The controller signal is applied to the grid of the first half of the tube V122. R157 is a grid leak resistor. Plate current flowing in R161 biases the cathode, thus making the cathode more positive than the grid. C138 is an RF bypass capacitor.

The signal is amplified in the first half of the tube and the a-c component is passed to the grid of the second half through capacitor C140. The second stage also provides voltage amplification. R163 is the cathode biasing resistor and R165 is the grid leak. The a-c component of the amplified signal is passed to the grid of V124 through coupling capacitor C142.

The output stage consists of *V*124 and *V*126, acting together in push-pull. Plate voltage is obtained from a 270-volt d-c supply. For push-pull operation, two signals equal in magnitude but opposite in polarity must be applied to the grids of the two tubes. Part of the output of *V*124 must therefore by applied to *V*126. The input to *V*124 is the voltage across *R*169.

The voltage across *R*173, which is part of the voltage-divider network *R*171 and *R*173, constitutes the input to the grid of *V*126. *C*144 is a d-c blocking capacitor. Both cathodes are self-biased through the biasing resistor *R*127. Proper polarity exists for the necessary push-pull actions because of the phase shifting that occurs in *V*124. The output is taken from the plates of *V*124 and *V*126 through the output transformer *T*107. Part of the output of *T*107 is fed back degeneratively to the grid of the first half of *V*122 by way of feedback resistor *R*127. This feedback takes the place of the rate generator, which was discussed earlier in the chapter.

When the output of *T*107 energizes the variable field of the servomotor, the motor will rotate in such a direction to cause the searchlight reflector to move in azimuth. Its direction depends on the phase relationship of the output signal of the controller. As the servomotor moves its load (reflector), it will also cause the followup rotor to move. This movement causes a change in the magnetic field of the stator of the indicator and the stator of the controller.

As the magnetic field changes in the indicator stator, it will cause the indicator rotor to follow and to aline itself with the resultant magnetic field. The indicator rotor has a pointer attached to it. This pointer sweeps a graduated dial as the rotor moves, indicating the position of the reflector in azimuth.

At the same time, the changing magnetic field in the controller stator causes the output signal of the controller to become smaller. When the servomotor has moved to the position first selected by the controller, the followup will cause the resultant magnetic field in the controller stator to cut the rotor at a right angle, thus nulling the signal output of the controller.

Capacitor-Type Fuel Quantity System

The capacitor-type fuel quantity system is discussed in *AE 3 & 2*, NavPers 10348. A further discussion of the operation of the amplifier and signal circuit is necessary in order to fully understand the servomechanism components of this system.

The main difference between this servo system and the searchlight servomechanism is that a potentiometer rather than a synchro is used to obtain a followup signal. Figure 7-15 shows the complete schematic diagram of a capacitance fuel gage system used in a modern naval aircraft.

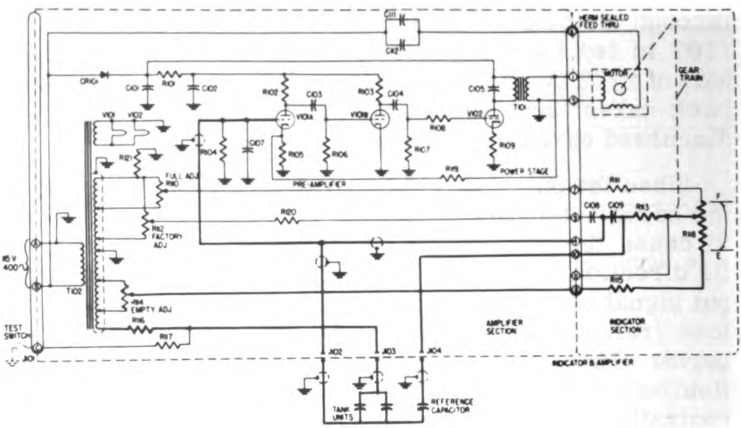


Figure 7-15.—Complete schematic diagram of fuel quantity system.

The system consists of four main units or sections—the tank units (capacitors installed in fuel tanks), the reference capacitors (installed outside of fuel tanks), the amplifier section, and the indicator section.

The fuel gage system operates on the bridge-circuit principle. (If you are not familiar with this operation, it is suggested that you review pertinent sections of chapter 14 of *AE 3 & 2*, NavPers 10348.) Anytime the bridge circuit becomes unblanced, the preamplifier section of the amplifier receives a signal, causing a small servomotor located in the indicator to rotate. The direction of rotation depends on the phase relationship of the bridge-circuit

signal. As the servomotor rotates, it causes the indicator pointer to move over a graduated dial (calibrated in pounds of fuel), and also causes a wiper arm of a potentiometer to move. The movement of the potentiometer arm causes the bridge circuit to again become balanced (acts as followup).

A typical system will be described in order to acquaint you with the various circuits. (Refer to fig. 7-15.) The amplifier section consists of a preamplifier stage and a power stage. The power supplies for the tubes are obtained from transformer *T*102; rectifier *CR*101 supplies half-wave rectification. The signal input and output of the preamplifier stage is controlled by R-C networks. The output of the power stage is coupled to transformer *T*101. Transformer *T*102 has the following three functions: (1) it supplies plate voltage for the tubes, (2) it supplies 115 volts, 400 cycles to the fixed phase of the servomotor, and (3) it supplies reference voltage for the bridge circuit. Transformer *T*101 supplies voltage to the variable phase of the servomotor. Capacitors *C*111 and *C*112 are phase shifting capacitors; these assure maximum efficiency of the servomotor.

The indicator section consists of a two-phase servomotor, a gear train connecting the motor to the indicator pointer, and a potentiometer wiper. The wiper moves over a potentiometer that supplies followup signal. The tank units and the reference capacitor form the bridge circuit. One side (*J*103) of the tank unit is connected to the secondary of transformer *T*102. *J*104 connects a side of the reference capacitor to the secondary of *T*102. This connection is through the potentiometer in the indicator. The remaining sides of the tank units and the reference capacitor are connected to the grid of the preamplifier through *J*102. (NOTE: The dark lines in figure 7-15 indicate the bridge circuit.)

When the fuel tanks are empty, the capacitance of the tank units and the capacitance of the reference capacitor are the same. Thus, no signal is developed across resistor *R*104. If the fuel tanks are being filled, increase of current through the tank unit half of the bridge circuit will occur. This is due to the increase in capacitance of the tank units, resulting in an unbalanced bridge. An unbalanced bridge causes a signal to be developed across

resistor *R*104. The signal will be amplified by *V*101a and *V*101b. It then goes through one stage of power amplification and is sent to the primary of transformer *T*101. The secondary output of *T*101 produces a voltage of the proper magnitude and phase relationship, which causes the servomotor rotor to rotate in the full position. At the same time the motor rotor, through a gear train, causes the potentiometer wiper to be moved in the full direction, thus increasing the voltage applied to the reference capacitor circuit. As the reference capacitor voltage increases, an increase in current in the reference capacitor half of the bridge circuit causes the signal across *R*104 to become smaller. When the fuel tanks stop receiving fuel, the potentiometer will move until there is enough current flow in the reference capacitance circuit to cancel the current flow in the tank unit circuit. At this time the signal across resistor *R*104 is zero.

As fuel is being used from the fuel tanks, the capacitance of the tank units decrease, thus allowing the reference capacitor circuit to develop a signal across *R*104 of opposite phase relationship. Again the signal is amplified and sent to the variable phase of the servomotor, causing it to rotate in the empty direction. This also causes the voltage applied to the reference capacitance circuit to decrease. The servomotor in the indicator will rotate until the two signals (tank unit signal and reference capacitor signal) are equal. The only time this will happen is when the fuel level is not changing.

The capacitance fuel gage system indicator will indicate the fuel remaining after a flight, or up to the time the electrical power was turned off. Since aircraft are usually filled after each flight, with electrical power off, the indication will not again be accurate until electrical power is again turned on.

QUIZ

1. In a servomechanism system, the input controller
   a. controls the gain of the amplifier
   b. controls the remotely located load
   c. provides the power to the servomotor
   d. provides the amplification of the error signal

2. What is the function of the data-transmission system?
   a. It is used for comparing the input signal with the output function of the controller
   b. It transmits a signal from the input signal generator to the control transformer
   c. It transmits a signal to the controller
   d. It is used to measure an error signal

3. In a servomechanism system, when the amplifier's gain is advanced too far, the
   a. servomotor overheats
   b. system goes into a highly oscillatory condition
   c. system's natural frequency decreases
   d. speed of response to the transient inputs decreases

4. The stator of the synchro has
   a. three windings spaced 120 electrical degrees apart
   b. two windings 180 mechanical degrees apart
   c. sliprings
   d. a voltage that is induced into the transmitter rotor

5. The searchlight controller described in this chapter contains two synchros which are used for
   a. azimuth and elevation control
   b. azimuth and rudder control
   c. elevator and reflector control
   d. rudder and reflector control

6. The automatic control system most often used is the
   a. open-loop system
   b. closed-loop system
   c. combination open- and closed-loop system
   d. system that does not have a feedback loop

7. One method of stabilizing a servo system is by
   a. decreasing the friction of the system
   b. increasing the power to the servomotor
   c. increasing the system's damping
   d. increasing the amplifier gain

8. The purpose of the phase sensitive rectifier is to
    a. change the d-c error to an a-c voltage
    b. supply power to the controller
    c. change the a-c error signal to a d-c voltage
    d. reduce the servo amplifier's output to zero when the input is zero
9. The input frequency to the amplifier shown in figure 7-14 is
    a. 400 c.p.s.
    b. 200 c.p.s.
    c. 180 c.p.s.
    d. 60 c.p.s.
10. Which of the following best describes the synchro?
    a. Large size, low accuracy
    b. Low power consumption
    c. High accuracy, low noise level, long life
    d. High driving torques
11. The most common method of electrical damping is accomplished by
    a. using a rate generator
    b. increasing the amplifier gain
    c. decreasing the voltage to the fixed phase of the servomotor
    d. using a larger servomotor
12. Potentiometer-type detecting elements are characterized by
    a. small size and low accuracy
    b. the fact that they can be used with both a-c and d-c voltages
    c. the fact that they possess long life as compared to a synchro
    d. low driving torque
13. Referring to figure 7-15, transformer *T*101 has which of the following functions?
    a. It supplies 115 volts, 400 cycles to the fixed phase of the servomotor
    b. It supplies the plate voltage to the tubes
    c. It supplies voltage to the variable phase of the servo
    d. It supplies the reference voltage to the bridge circuit
14. In a servomechanism system, the output controller
    a. is the component or components where electric power is converted to mechanical power
    b. converts mechanical motion into power to drive the load
    c. provides a means of control of the input controller
    d. provides an error signal to the amplifier

15. The followup synchro in figure 7-9 is positioned so that its magnetic field
   a. induces a minimum voltage into the stator at the null position
   b. induces a maximum change in voltage at null
   c. induces the maximum flux into the stator at null
   d. is zero at null

16. The output of a discriminator is
   a. a.c.
   b. d.c. without an error signal
   c. zero with an error signal
   d. zero when the error signal is zero

17. Referring to figure 7-14, the purpose of the capacitor in series with the servomotor's fixed field is to
   a. resonate the circuit
   b. limit fixed field current
   c. limit motor speed
   d. provide necessary field shift

18. The error signal is the
   a. input to the controller shaft
   b. distance that the controller shaft has moved
   c. input to the servomotor
   d. difference between the servomechanism input and output

19. Three types of motor drives that are used extensively in positioning systems are the
   a. a-c, d-c, and shunt motor
   b. hydraulic, shunt, and induction motor
   c. a-c, d-c, and hydraulic motor
   d. shunt, induction, and shaded-pole motor

20. Most servo amplifiers are divided into how many sections?
   a. One
   b. Two
   c. Three
   d. Four

21. The main difference between the servo system used in the capacitor-type fuel quantity system and that used in the searchlight system is:
   a. a potentiometer is used in place of a synchro for the followup signal
   b. the number of amplifier stages
   c. no difference exists between them
   d. a rate generator is used for the feedback signal

22. The magnetic amplifier in figure 7-7
  a. consists of two sets of single windings
  b. allows the primary winding to control the flux in the core
  c. has its secondary windings connected series-aiding
  d. can be considered as two transformers

CHAPTER 8

INTRODUCTION TO TRANSISTORS

The transistor is relatively new to the field of electronics. During the past few years it has been a much talked about subject. Its development has been rapid, and it is already being used in many different fields of naval aviation. As an Aviation Electrician, you should be familiar with transistors since they are being used in some of the equipment that you are required to maintain. For example, they are replacing many of the electron tubes that are used in various types of amplifiers. As further developments are made, you can expect to find that transistors will be used more extensively.

As compared to an electron tube, the transistor has a higher operating efficiency and is much smaller in size. One of its greatest advantages is that no filament voltage is required; therefore, no filament power supply is needed. In the electron tube, over one-half of the power required to operate the tube is consumed in the filament power circuit. Since there is low power consumption in the transistor, there will be less heat radiation. This is advantageous since it allows transistorized equipment to be built more compact, thereby conserving critical aircraft space. Another advantage of the transistor over the electron tube is its ability to operate instantly; no preheating period is required. Because of its solid-state construction, the transistor can withstand acceleration and deceleration forces many times the force of gravity. Transistors are extremely rugged and long lived and

require little maintenance as compared with electron tube equipment.

Figure 8-1 shows, in actual size, some typical transistors that are used in the field. Note their size as compared to an electron tube.

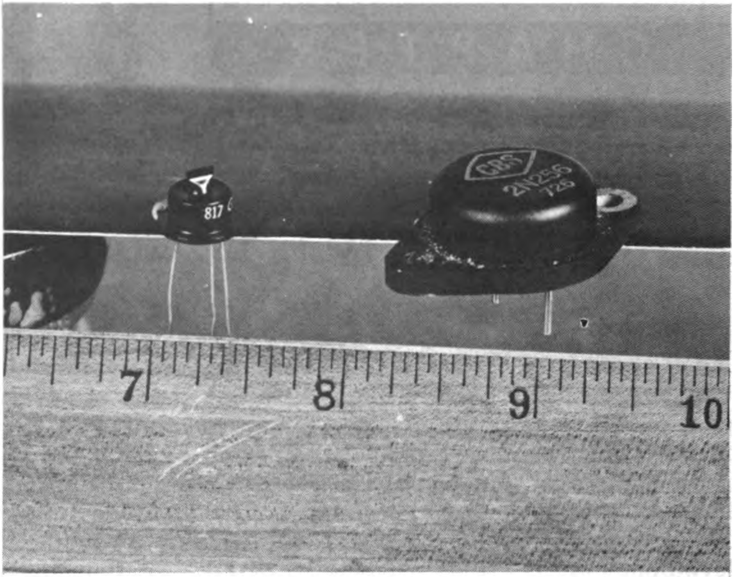


Figure 8-1.—Typical transistors.

This chapter presents the fundamental theories of operation of transistors. It also describes their properties and shows their application in some of the basic circuits of aircraft electrical equipment.

In order for you to understand the information presented in this chapter you must possess a knowledge of the basic theories of atomic structure. These are given in chapter 1 of *Basic Electricity,* NavPers 10086.

SEMICONDUCTORS

A semiconductor is a solid material that has a greater amount of conductivity than an insulator and less conductivity than a conductor. Some semiconductors are

compounds, such as copper oxide and zinc oxide, while other semiconductors are elements, such as germanium and silicon. Silicon and germanium, when combined with certain impurities, are still classed as semiconductors. There are other materials that exhibit semiconductor properties, but since germanium and silicon are used extensively in the manufacture of transistors, the theory presented here will deal only with these two materials.

Figure 8-2 shows the resistive relationships of various insulators, semiconductors, and conductors. Note the resistive relationships between intrinsic silicon (pure silicon), intrinsic germanium (pure germanium), transistor germanium, and impure germanium.

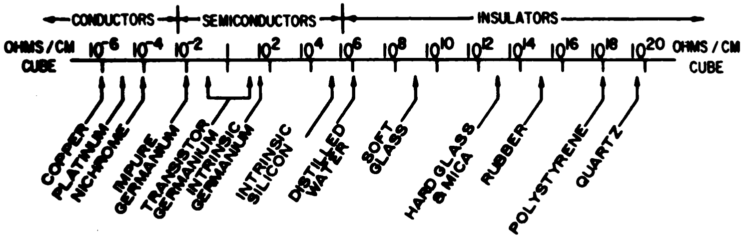


Figure 8-2.—Resistivity chart of common conductors, semiconductors, and insulators at 68° F.

ATOMIC STRUCTURE OF GERMANIUM AND SILICON.—An atom of germanium has 32 electrons distributed in 4 rings about its nucleus while the atom of silicon has 14 electrons distributed in 3 rings about its nucleus. (See fig. 8-3.) The inner rings of these elements (1st, 2nd, and 3rd rings of germanium and 1st and 2nd rings of silicon) are said to be complete and will not accept any more electrons. Electrons may be removed from the rings, but considerable energy would be needed to do so. This leaves only the outer electron ring of the atoms to be considered.

The outer ring of any atom determines the electrical and chemical characteristics of that atom. The core (inner rings and nucleus) of the atom is considered to be completely inactive. The electrons in the outer ring of an atom are called valence electrons. To classify elements according to their electrical and chemical

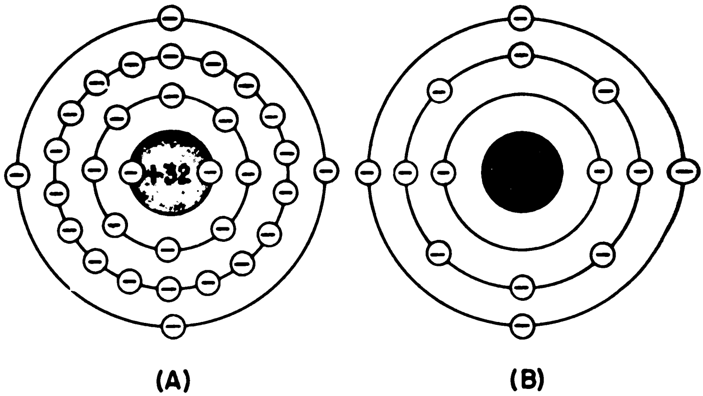


Figure 8-3.—Plan view of (A) the germanium atom and (B) the silicon atom.

characteristics, they are placed into categories. One of these categories classifies the elements according to the number of valence electrons present in their atoms. The atoms of germanium and silicon are classified as tetravalent because they each have four valence electrons.

When one or more electrons are removed from an atom or added to an atom, the atom is no longer electrically neutral in charge. A neutral atom of silicon, for example, has 14 protons in its nucleus and 14 electrons in its rings. If this silicon atom loses one of its valence electrons, it becomes a positive ion with a net charge of +1 (14 protons and 13 electrons). However, should the silicon atom take on an electron, it will become a negative ion with a net charge of -1 (14 protons and 15 electrons). (NOTE: The adding of electrons to electrically neutral atoms is usually confined to chemical activity.)

An application of energy is necessary to remove an electron from an atom. The forms of energy commonly used in electronics are: (1) electric fields (e. m. f. that causes electron flow in a conductor), (2) heat (cathode of a vacuum tube), (3) light (photoelectric cell), and (4) bombardment by other particles (thyratron operation). The amount of energy needed to move an electron from the atoms of different elements varies with the elements. For example, more energy is needed to remove an electron from the silicon atom than is needed to remove an electron from the germanium atom.

CRYSTAL STRUCTURE OF GERMANIUM AND SILICON.—In their pure solid state, intrinsic germanium and silicon are crystals in the shape of cubes. Each of the four valence electrons of an atom form bonds with an electron from one of the four nearest atoms. These bonds of paired electrons, called covalent bonds, provide the force that binds the atoms together to form the crystal structure. Any crystal is a regular array of atoms; and in the case of germanium and silicon, this regular array of atoms forms a tetrahedral crystal. Figure 8-4 shows a three-dimensional crystal structure of germanium and silicon. The rods connecting the atoms represent the covalent bonds between the atoms.

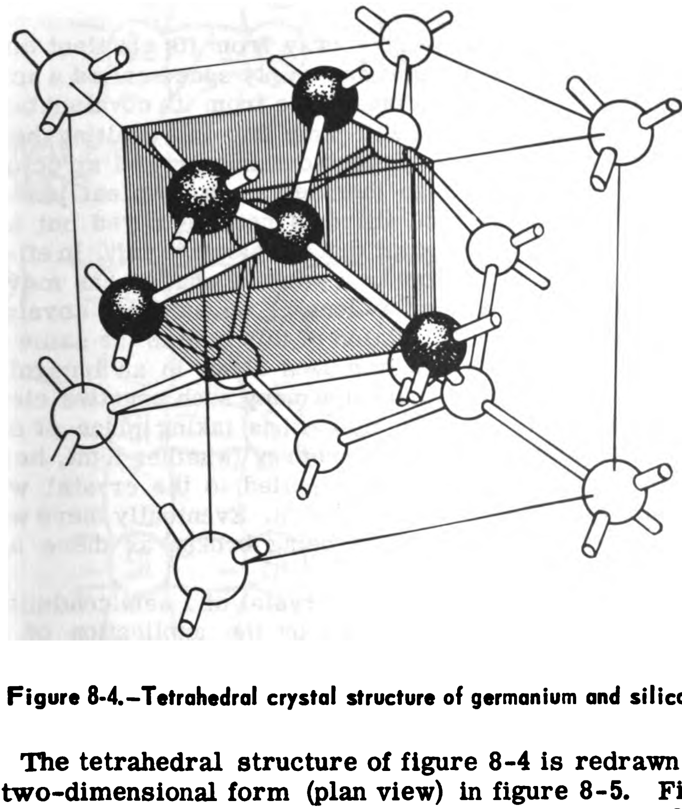


Figure 8-4.—Tetrahedral crystal structure of germanium and silicon.

The tetrahedral structure of figure 8-4 is redrawn in a two-dimensional form (plan view) in figure 8-5. Figure 8-5 (A) shows the germanium crystal and figure 8-5

(B) shows the silicon crystal. Note that all atoms are equidistant from each other and that between the cores of any two atoms there are two valence electrons.

In the crystal structure of intrinsic germanium and silicon, the forces of attraction and repulsion between atoms and electrons balance each other. Due to thermal agitation at ordinary room temperatures (68° F.), some electrons gain sufficient energy to break their covalent bonds and become free. These free electrons will allow some conduction (current flow) when an e.m.f. is impressed across the crystal.

Hole and Electron Flow

When an electron breaks away from its covalent bond and becomes free, it leaves an empty space called a hole. If a nearby electron becomes free from its covalent bond by thermal agitation, it will jump into this waiting hole. (NOTE: This is because electrons in a crystal structure always seek to arrange themselves in covalent pairs.) The hole this electron filled is not destroyed but has merely moved to the point that the electron left. In effect then, the hole, which acts as a positive charge, has moved and will keep on moving as long as an adjacent covalent electron is freed. The action of this hole is the same as the free electron in that it moves about in an irregular manner. In a crystal there are many such negative electron and positive hole combinations taking place at one time. At the same time, the energy (whether light, heat, or an electric field) being supplied to the crystal will constantly be breaking other bonds. Eventually there will be as many covalent bonds being broken as there are being reformed.

If the energy supplied to a crystal of a semiconductor is an electric field developed by the application of an e.m.f. across this crystal, the random movement of the electrons and the holes will be less, and they will be directed along the lines determined by the e.m.f. The electrons will move toward the positive terminal while the holes will drift toward the negative terminal. The action of the hole and electron flow is additive and represents the total current flow through the crystal.

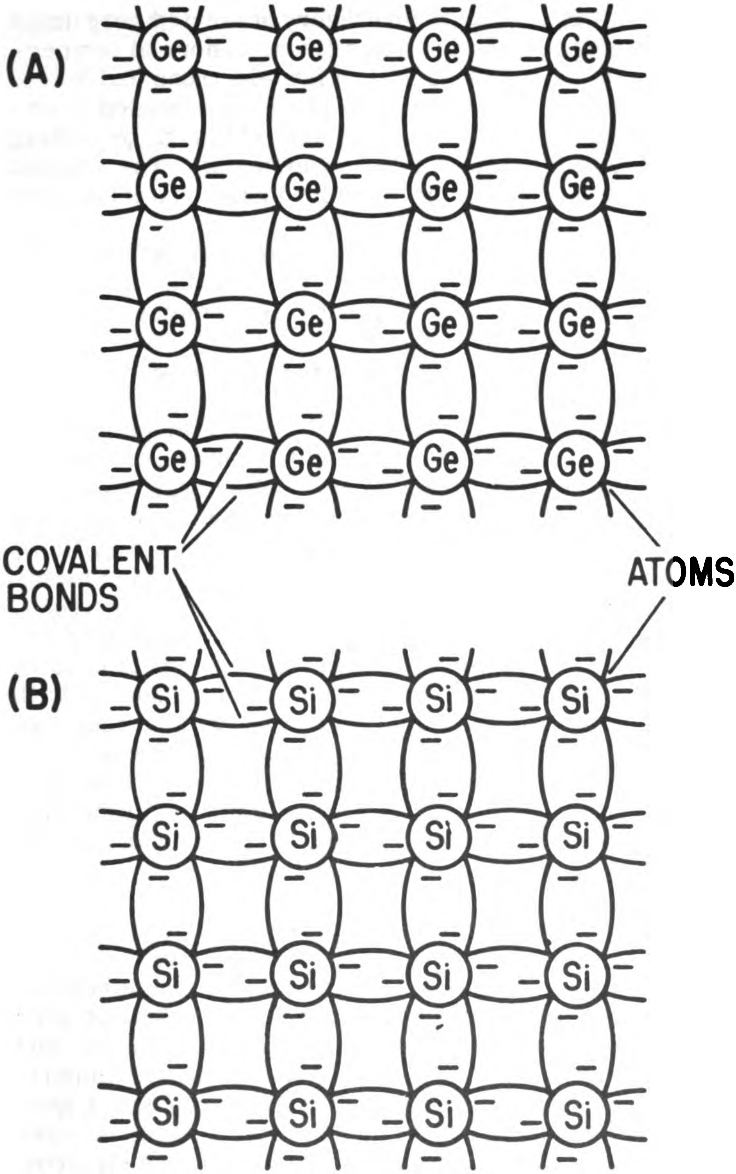


Figure 8-5.—Two-dimensional view of (A) the germanium crystal and (B) the silicon crystal.

The hole and electron flow theory presented here deals with intrinsic germanium and silicon. In normal temperature these materials have very few electrons and holes. Large numbers of electrons and holes are needed to obtain transistor action. These are obtained by adding impurities to the semiconductor material. The amount of impurities added to the semiconductor materials are carefully controlled.

There are two types of materials produced by the addition of impurities to silicon or germanium. These materials are known as *N*-type and *P*-type semiconductors.

N-Type Semiconductor Material

If an impurity such as arsenic is mixed with germanium or silicon, many free electrons will be produced. This is because the atom of arsenic is pentavalent (has five valence electrons); and when introduced into germanium or silicon in very small amounts (one part in one million), displaces some atoms of germanium or silicon and forms four covalent bonds by using four of its valence electrons. (See fig. 8-6 (A).) The extra electron has no adjacent electron with which to form a covalent bond; thus it is free to move within the crystal. A semiconductor with excess electrons, such as germanium with arsenic, is called an *N*-type semiconductor material because its current carriers are electrons. The impurities that produce many free electrons in germanium or silicon are called donors. Some other impurities that can be used as donors are phosphorus and antimony.

P-Type Semiconductor Material

By adding impurities that have three valence electrons (trivalent) instead of five, a semiconductor will be produced that has an excess of holes. Boron, gallium, and indium are examples of such substances used as impurities. Each trivalent impurity atom will replace a germanium or silicon atom in the crystal structure. (See fig. 8-6 (B).) There is now a deficiency of one electron; and in order to complete the four covalent bonds, the trivalent atom attracts an electron from a nearby germanium or silicon bond. This results in a hole being left

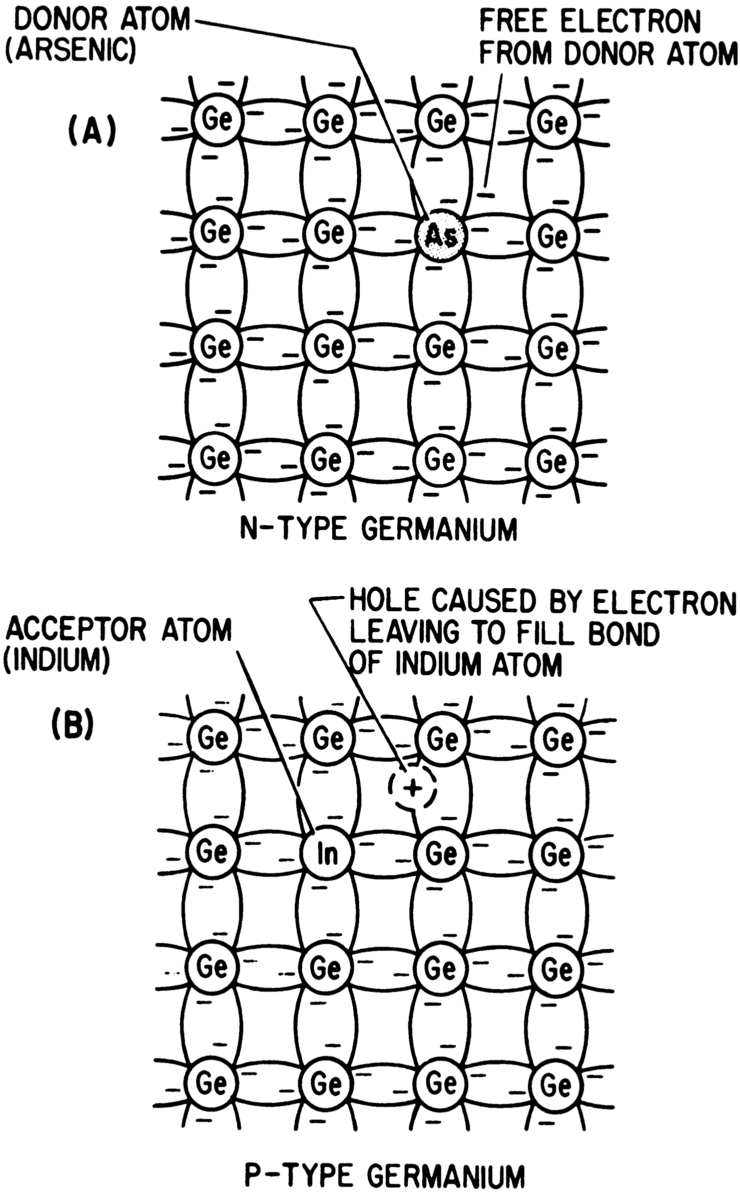


Figure 8-6.—(A) Germanium with a donor atom; (B) germanium with an acceptor atom.

in the adjacent covalent bond. When a very small amount (one part in one million) of trivalent impurities, called acceptors, are added to intrinsic germanium or silicon a series of holes are produced and the material is called a *P*-type semiconductor.

When an e.m.f. is applied across a *P*-type semiconductor crystal, the holes move toward the negative potential or terminal. This is brought about by a hole attracting an electron from a nearby covalent bond. When this electron leaves a covalent bond, the bond is broken leaving a hole. In effect then, the hole has moved from one position to another. This movement or drift of the hole continues on through the material and towards the negative field or potential.

As the holes reach the negative terminal, they are filled in by electrons flowing from this terminal. At the positive terminal an equal number of holes is created by electrons being pulled into the positive terminal. The crystal is now conducting current, and this current is considered to be a flow of holes from the positive to the negative terminal.

In the following explanations of semiconductor diodes and transistors, only the germanium types will be discussed. (NOTE: Silicon types of diodes and transistors could just as well be used in this discussion since the same theories of operation pertain to both germanium and silicon materials.)

Semiconductor Diodes

PN JUNCTIONS.—When *N*-type germanium and *P*-type germanium are combined, as shown in figure 8-7, a germanium junction diode is formed. To combine *N*-type to *P*-type germanium does not mean that two materials are mechanically fitted together. To make a satisfactory junction, a single crystal must be formed with both *P*-type and *N*-type characteristics. There are two methods of combining the two types of material; these are known as the fused junction and the grown junction methods.

A grown junction (fig. 8-7 (A)) is formed by growing a single crystal from a melt. At the start the melt contains donor impurities and *N*-type material is formed. In

the middle of this forming process, acceptor impurities are added to form the *P*-type portion of the crystal.

The fused junction diode (fig. 8-7 (B)) is formed by placing a small amount of indium on a slab of *N*-type germanium. This combination is then heated to a specific temperature for a certain amount of time so that the indium fuses to the germanium. This fusion produces a

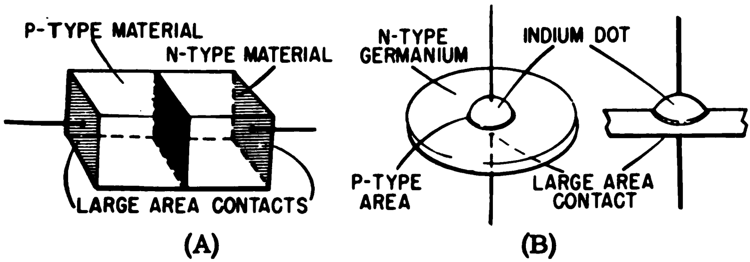


Figure 8-7.—Junction diodes: (A) Grown; (B) fused.

P-type area of germanium in the slab immediately below the indium dot.

OPERATION OF PN JUNCTION DIODE.—When there is no voltage applied to the *PN* junction diode, there is a deficiency of electrons and holes at the junction of the *P*-type and *N*-type material. This is because the electrons and holes in this junction area have combined. It might seem that the combining of holes and electrons would continue until there were no longer any holes or electrons left. However, this is not the case. After the initial combining of holes and electrons at the junction, a potential barrier is produced. Figure 8-8 illustrates the formation of the barrier.

After the combining of the holes and electrons (fig. 8-8 (A)), positive and negative ions will be uncovered (fig. 8-8 (B)). An electrical field is set up at the junction of the *P* and *N* material because of these ions. (NOTE: To better understand how the positive and negative ions are produced refer to figure 8-6. In the (A) portion of this figure a donor atom of arsenic is changed into a positive ion when the free electron is moved away from this area. Likewise, in part (B) the acceptor atom of indium is changed to a negative ion when the hole is moved away from this area.) The positive ions at the

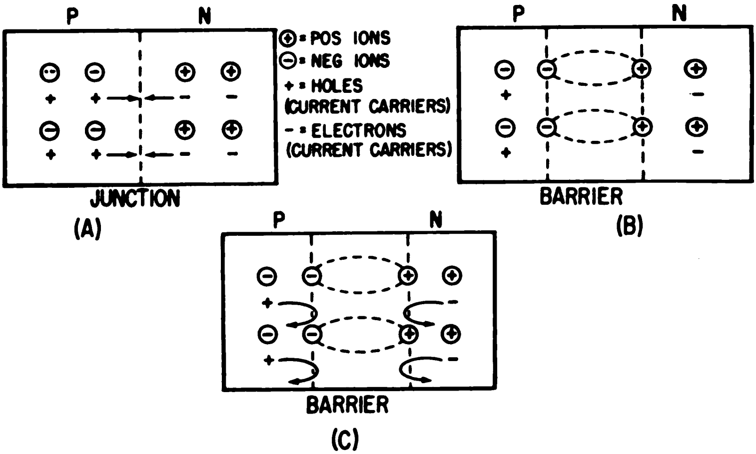


Figure 8-8.—PN junction formation of barrier by ions.

barrier will repel the holes in the *P* material, while the negative ions will repel the electrons in the *N* material. It may be noted here that the actual barrier developed is only a few centimeters thick. This thickness determines the barrier level or barrier potential.

In order to produce a flow of current across the barrier, the barrier's electrical field or potential must be neutralized. This can be done by applying an external potential across the ends of the *PN* diode. (See fig. 8-9 (A).) The negative terminal of the battery is connected to the *N* side of the diode while the positive terminal is connected to the *P* side. This particular connection to the diode is called the forward bias connection. The free electrons in the *N* section are repelled by the applied negative field and they will move toward the *PN* junction. At the same time, the holes in the *P* section are repelled from the positive field, forcing them toward the junction. If this applied potential is large enough, it will overcome the barrier potential and enable the holes and electrons to move to the opposite sides of the barrier. As the barrier crossing is made, the electrons and holes will combine, allowing current to flow through the *PN* diode. (NOTE: New holes are produced at the positive terminal by electron removal and at the same time electrons are introduced into the *N* material from the negative terminal.)

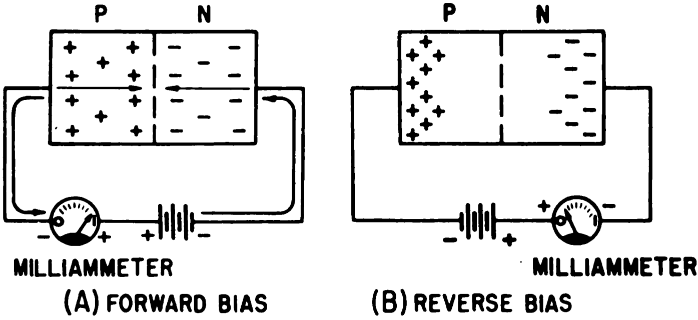


Figure 8-9.—Forward bias and reverse bias applied to the PN junction.

In the preceding explanation the *PN* junction diode was biased in the forward or low resistance direction. When the polarity of the applied voltage is reversed, the diode will be biased in the high resistance direction or it will have what is called reverse bias applied to it. (See fig. 8-9 (B).) This reverse bias actually increases the potential barrier that is present at the *PN* junction. The positive terminal that is connected to the *N* side of the diode will attract the electrons (current carriers) in the *N* material. Likewise, the negative terminal will attract the holes in the *P* material. Due to these conditions, holes and electrons cannot combine with each other, resulting in only a minute amount of current flowing in the diode. This small amount of current is caused by current carriers called minority carriers. These minority carriers are electrons and holes, resulting mainly from thermal agitation, and are located on the wrong side of the junction; that is, holes are located in the *N* material and electrons are located in the *P* material. Due to the locations of these minority current carriers, they are not in opposition to the applied potential and will therefore move across the junction, causing some current flow.

POINT-CONTACT DIODES.—Figure 8-10 (A) shows a cutaway view of a point-contact diode. The theory of operation of the point-contact diode is the same as the theory of operation of the *PN* junction diode. The difference between the two diodes is their physical construction and use.

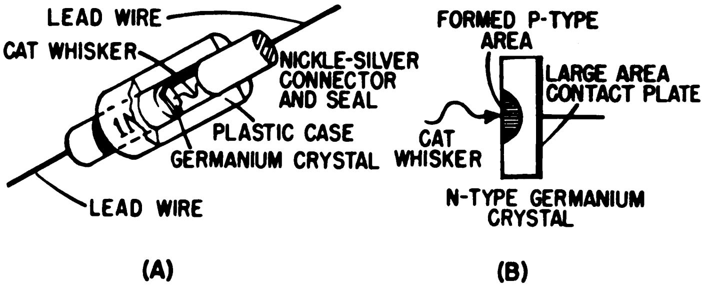


Figure 8-10.—(A) Cutaway view of a point-contact diode; (B) point-contact diode showing P-type area in the N material.

The construction of the point-contact diode usually begins with a small square of *N*-type germanium with a phosphor-bronze or beryllium-copper "cat whisker" pressed against the center of one side of the crystal. A metal plate is connected to the other side of the crystal face. This plate provides electrical contact to the *N* side of the crystal.

The actual diode is formed by passing a large amount of current from the "cat whisker" to the *N*-type germanium slab. The result of this current flow is that a small area of *P*-type germanium is formed in the region surrounding the contact area of the "cat whisker" (fig. 8-10 (B)). The point-contact diode now consists of both *P*-type and *N*-type germanium.

SEMICONDUCTOR DIODE APPLICATIONS.—Semiconductor diodes are being used to do many jobs in the field of electronics that were previously done by other types of rectifiers. Junction diodes of silicon and germanium may be used in high power applications (hundreds of amperes) as well as low power applications (milliamperes). Point-contact diodes are usually used as low power rectifiers, detectors, mixers, clampers, clippers, and so forth. Both junction and point-contact diodes are very efficient and compact as compared to other types of rectifiers.

Figure 8-11 (A) shows the symbol used for semiconductor diodes. Electron and current flow is against the arrow. (NOTE: There are two theories on electron and current flow. One is that current flows in the opposite

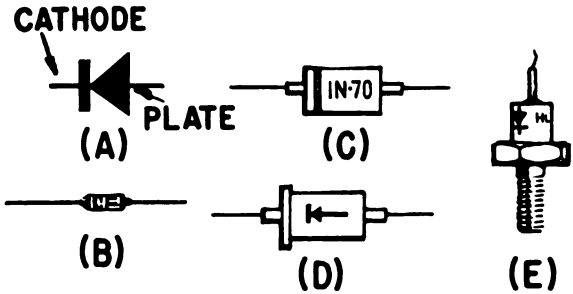


Figure 8-11.—(A) Symbol for semiconductor diodes; (B), (C), (D), and (E) typical diodes, actual size.

direction of electron flow. The other theory and the one accepted by the Navy is that electron flow and current flow are in the same direction.) In the symbol used for semiconductor diodes, electron flow is against the arrow; therefore, it must be accepted that current flows in this same direction.

Comparing the semiconductor diode to a vacuum-tube diode, the straight bar of the symbol is considered the cathode (*N* material), while the arrow represents the plate (*P* material).

Figure 8-11 (B), (C), (D), and (E) shows some typical semiconductor diodes; these are shown in actual size. These drawings also show different methods that are used to identify the cathode connection. In (B) and (C) of figure 8-11 the end marking band is nearest the cathode end, while in (D) and (E) the cathode is indicated by the semiconductor symbol.

Care and installation of semiconductor diodes is discussed in chapter 14 of this training course.

TRANSISTOR THEORY

At present, there are many different types of transistors in use and many other types in the developmental stage. Some of the transistors that are in use are the point contact, junction, drift, tetrode, field effect, hook, point junction, fieldistor, and surface barrier. Each has its own unique characteristics, advantages, and areas of application.

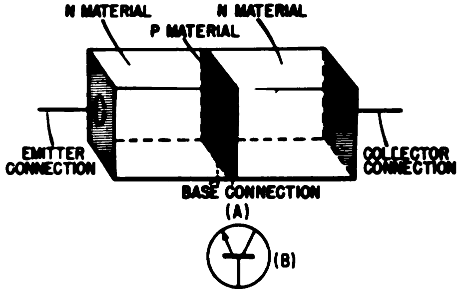


Figure 8-12.—(A) NPN transistor, grown-junction type; (B) symbol for NPN transistor.

Since the junction transistor (*PNP* and *NPN*) is the most commonly used, its theory of operation will be thoroughly discussed.

There are two basic types of junction transistors, the *NPN* and *PNP*. Since there is a difference in direction of current flow and required voltage polarity in these two types of junctions, they will be discussed separately.

NPN JUNCTION TRANSISTOR.—The *NPN* junction transistor (fig. 8-12) is actually a *PN* junction with another section of *N*-type material formed to the *P* section of the junction. As in the construction of *PN* diodes, there are two main methods used in forming the junction transistors, the grown junction (usually *NPN*) and the fused junction (usually *PNP*).

The junction transistor is composed of three sections, the emitter, the base, and the collector. (See fig. 8-12.) The emitter emits current carriers into the base region of the transistor; the collector collects most of these current carriers from the base region. The base is a common point for biasing the collector and emitter. In the *NPN* transistor the emitter and collector are made of *N*-type material and the base is made of *P*-type material.

The forward bias is applied between the base and emitter (negative polarity connected to the emitter and positive polarity to the base). As will be seen later, this emitter bias will control the amount of current through the transistor. Figure 8-13 (A) shows the *NPN* transistor with only emitter bias connected to it. Notice that the direction of current flow (I_e) is the same as in the

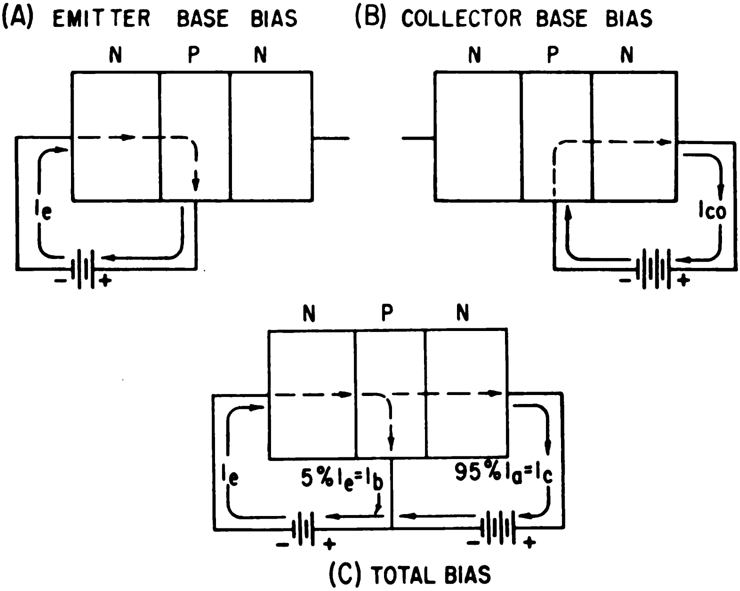


Figure 8-13.—Bias applications to an NPN transistor.

PN-junction diode with forward bias. The electrons in the *N* material and the holes in the *P* material will combine at the junction to cause current to flow from the negative potential to the positive potential of the bias supply.

Reverse bias is applied between the base and collector (negative polarity connected to the base and positive polarity connected to the collector). Figure 8-13 (B) illustrates the reverse bias connection to the *NPN* transistor. Under this condition with only reverse bias applied, the collector current (I_c) will be zero. There is, however, a current flow called I_{co} flowing in the collector circuit. As in the *PN* junction with reverse bias, this current is caused by minority carriers. I_{co} designates collector current when there is NO emitter current.

Figure 8-13 (C) shows both biases connected. Most of the emitter current (I_e) flows through the base to the collector material. This current flows in the collector and becomes collector current (I_c). The current (electrons) flows through the base because of two reasons. First, the base is very thin (0.001 inch); and second, the

positive attracting force of the collector potential impels the electrons through the base.

In figure 8-13 (C) it can be seen that the emitter and collector bias batteries are connected in series-aiding so that the circuit for electron flow from the emitter through the base and to the collector is complete. Probably no more than 5 percent of the emitter electrons combine with the holes in the base. The remaining emitter electron flow (95 percent) passes through the base into the collector material.

The number of electrons leaving the emitter depends entirely on the emitter base bias. This current is varied by changing the emitter bias voltage. Since the base current is very small, a change in emitter bias will have a far greater effect on the emitter-collector current than on the base current. (NOTE: The collector can be compared to the plate of an electron tube, the emitter can be compared to the cathode, and the base compared to the grid.)

The transistor's ability to amplify lies in the fact that there is a difference in the emitter-to-base resistance $(r_e + r_b)$ and collector-to-base resistance $(r_c + r_b)$. The emitter resistance is very low (500 ohms), because it is biased in the forward or low resistance direction. The collector resistance is extremely high (500,000 ohms), because it is biased in the high resistance or reverse direction.

Since collector current is 95 percent of emitter current, this gives the junction transistor a current gain of 0.95. (NOTE: Current gain is designated alpha and is figured by dividing collector current (I_c) by emitter current (I_e).) Using the current gain and the emitter and collector resistances, the approximate voltage and power gains of the junction transistor can be shown. If alpha $(\alpha) = 0.95$, $r_e + r_b = 500$ ohms, and $r_c + r_b = 500{,}000$ ohms then

$$\text{Voltage gain} = \alpha \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Voltage gain} = 0.95 \times \frac{500{,}000 \text{ ohms}}{500 \text{ ohms}}$$

$$\text{Voltage gain} = 0.95 \times 1{,}000$$

$$\text{Voltage gain} = 950$$

Using the above values of alpha, emitter base resistance, collector base resistance, and the power formula $P = I^2R$, the power gain can be shown.

$$\text{Power gain} = \frac{\text{Power out}}{\text{Power in}}$$

$$\text{Power gain} = \alpha^2 \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Power gain} = 0.95^2 \times \frac{500{,}000 \text{ ohms}}{500 \text{ ohms}}$$

$$\text{Power gain} = 0.9025 \times 1{,}000$$

$$\text{Power gain} = 902.5$$

Although the junction transistor can never have a current gain greater than one, the above examples show that the transistor is capable of producing voltage and power gains. The reason these gains are obtainable is because of the high collector resistance and the low emitter resistance.

Figure 8-14 shows an *NPN* transistor connected as an amplifier. An a-c signal source is connected in series with the base bias (B_2) and the emitter; a load resistor (R_L) is connected in series with the collector bias (B_2) and the collector.

With zero applied signal, the emitter and collector currents are dependent on the emitter base bias. If the

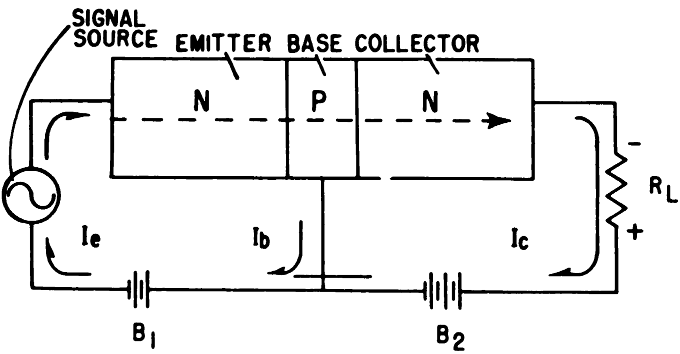


Figure 8-14.—NPN transistor connected as an amplifier.

applied signal goes negative, it increases the forward bias which increases emitter current. This increase in emitter current causes an increase in collector current which, in turn, causes a greater drop across R_L. When the signal at the emitter goes positive, the emitter base bias decreases, causing a decrease in emitter current, a decrease in collector current, and therefore a decrease in the voltage drop across R_L. In figure 8-14, signal amplification is obtained, but there is no signal phase shift or inversion between input and output. Later it will be seen that there are other methods of connecting a transistor in which there will be a signal phase shift (or inversion).

Since transistors are an entirely new approach to a means of amplification, with many new features and characteristics, it may cause some confusion to the technician who tries to compare the transistor with the vacuum tube point by point. A better understanding will result if you learn the operation of transistors by using only the terms and ideas that are common to transistors.

PNP JUNCTION TRANSISTOR.—The *PNP* transistor uses *P*-type material for the emitter and collector and *N*-type material for the base. Most *PNP* transistors are of the fused junction type.

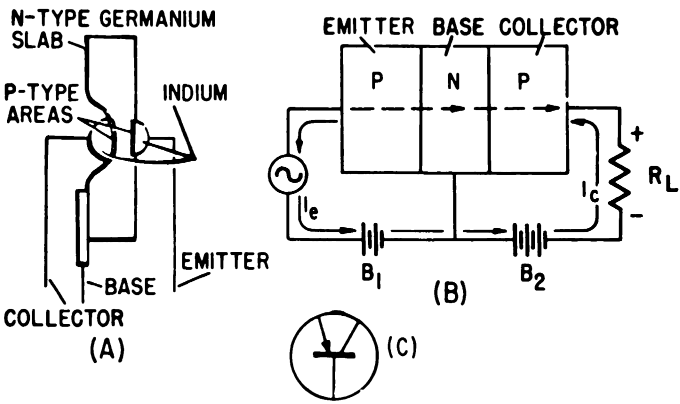


Figure 8-15.—(A) PNP junction transistor, fused junction, (B) bias connections to the PNP junction transistor, (C) symbol for PNP transistor.

As in the *NPN* transistor, forward bias is applied between the base and emitter and reverse bias applied between the base and collector (fig. 8-15 (B)). Since the emitter, base, and collector are made of opposite type materials to that used in the *NPN* transistor, the bias polarities are reversed. With the emitter and collector made of *P*-type material, the current carriers in the transistor will be holes. As in the *PN* junction diode, the current flow in the connecting wires consists of electrons.

The operation of the *PNP* transistor is the same as the *NPN* except the current flow is in the opposite direction. For example, in figure 8-15 (B) if a positive-going signal is applied to the emitter, it will add to the forward bias (B_1), causing an increase in I_e. This will increase hole flow to the collector, causing an increase in I_c and an increased voltage drop across R_L. (NOTE: I_c is normally referred to as negative current in the *PNP* transistor. The reason for this is to distinguish between *NPN* collector current and *PNP* collector current.) If the signal applied to the emitter is negative going, it will subtract from the emitter bias (B_1) and cause a decrease in emitter hole flow. Therefore, this will cause a decrease in I_c and a decrease in the voltage drop across R_L.

POINT-CONTACT TRANSISTOR.—The point-contact transistor is very similar to the junction transistor. The point contact was the first transistor developed; it is being replaced by the junction transistor. Most of the theory presented on the junction transistor will apply to the point contact.

The construction of a point-contact transistor is shown in figure 8-16 (A). In this transistor the emitter and collector connections are made through the pointed ends of very small electrodes. The points of these electrodes, which are spaced only a few thousandths of an inch apart, are connected to the base material. The base material may be either *P*-type or *N*-type germanium crystal. (NOTE: *N*-type material is the only material used to construct point-contact transistors that are used commercially.)

The *P*-type area for the emitter and collector is formed by passing a controlled amount of current from the emitter and collector wires to the base. The area formed in the *N*-type material by this method is very small. With an

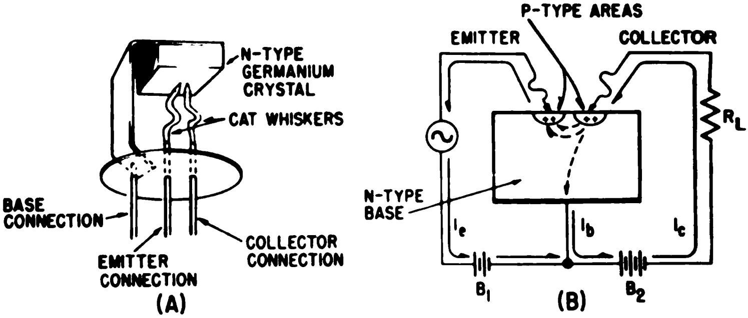


Figure 8-16.—(A) Point-contact transistor; (B) point-contact transistor with bias voltages applied.

emitter of *P*-type material, a base of *N*-type material, and a collector of *P*-type material, a transistor is produced whose theory of operation is similar to the theory used in the explanation of the junction transistor.

Referring to figure 8-16 (B), it can be seen that the bias voltages are connected to the point-contact transistor with the same polarities used in the connection of the *PNP* junction type; that is, forward bias from emitter to base and reverse bias from collector to base. With both of these biases applied there will be hole flow from the emitter through the base area into the *P* area of the collector (same as in the *PNP* transistor). Here the resemblance of operation between this point-contact transistor and the *PNP* junction transistor ends. In the junction transistor the collector current (I_c) would now be about 95 percent of the emitter current (I_e), but the collector current in this point-contact transistor measures anywhere from 2 to 3 times the emitter current. Thus, the point-contact transistor has an α (current gain) of around 2 to 3.

There is some doubt as to why the collector current is so much greater than emitter current. The theory presented on this point is very vague. It is generally believed that this additional current is caused by the moving holes forming a positive space charge in the base-to-collector area. The result of this space charge is to attract other electrons from the relatively large base area *N*- type material) and cause them to flow in the collector-to-base circuit. When this collector-to-base

current is added to the normal collector current, the result is a total collector current (I_c) of 2 to 3 times more than emitter current (I_e).

A typical voltage gain of a point-contact transistor can be shown by the same method used to figure the typical junction transistor's gain. In a typical point-contact type the emitter-to-base resistance $(r_e + r_b)$ is around 250 ohms and the collector resistance $(r_c + r_b)$ is around 25,000 ohms. Using these resistance values and an average alpha (α) of 2.5

$$\text{Voltage gain} = \alpha \times \frac{r_c + r_b \text{ (resistance of collector)}}{r_e + r_b \text{ (resistance of emitter)}}$$

$$\text{Voltage gain} = 2.5 \times \frac{25{,}000 \text{ ohms}}{250 \text{ ohms}}$$

$$\text{Voltage gain} = 2.5 \times 100$$

$$\text{Voltage gain} = 250$$

Comparing this gain with the gain of a junction transistor (950), it can be seen that the junction transistor has considerably more gain. The reason for this is because of the high collector resistance (r_c) of the junction transistor, which gives it a higher resistance gain.

The point-contact transistor also has power gain. As in the junction transistor, this can be proven by using Ohm's law $(P = I^2R)$.

$$\text{Power gain} = \frac{\text{Power out}}{\text{Power in}}$$

$$\text{Power gain} = \alpha^2 \times \frac{r_c + r_b}{r_e + r_b}$$

$$\text{Power gain} = 2.5^2 \times \frac{25{,}000 \text{ ohms}}{250 \text{ ohms}}$$

$$\text{Power gain} = 6.25 \times 80$$

$$\text{Power gain} = 625$$

(NOTE: The formulas that have been used give only approximate gains; they have been used for the purpose of explaining the operation of the junction and the point-contact transistor.)

Comparison of Point-Contact and Junction Transistors

FREQUENCY RESPONSE.—One of the factors that controls the frequency limits of a transistor is the time required for a signal to flow from the emitter to the collector terminals. This means that the frequency of the applied signal cannot be so great that it will not allow the carriers (holes or electrons) to carry these changes from the emitter to the collector before changing polarity. This condition is similar to that in an electron tube where the transit time is too long. (Transit time is the time required for an electron to travel from cathode to plate.)

Since electrons move almost twice as fast as holes, it can be expected that transistors with electrons as current carriers will respond best to high frequencies. The frequency response of *NPN* transistors is almost twice that of *PNP* transistors.

The transistor's high-frequency response is also affected by the capacitance of the junctions of the transistor. This characteristic is being improved by manufacturers who are developing newer and better techniques in the production of transistors.

Basically, the point-contact transistor has a somewhat higher frequency response than the junction type because distances that signals have to travel from emitter to collector are very small. In the last few years, however, junction transistors have been manufactured with frequency responses exceeding that of the point-contact type.

POWER DISSIPATION.—Junction transistors, as compared to point-contact transistors, may be produced so that they can handle much larger amounts of power than point-contact transistors. This is true because of the large contact area of the collector electrode of the junction transistor, which allows it to readily dissipate heat. In a point-contact transistor, the contact area between the collector and its "cat whisker" wire is very small.

There is a rapid rise in temperature because of this feature. Should the collector section become too hot, its internal resistance will decrease. The decrease in resistance will increase the collector bias current.

Junction power amplifiers have been produced that will handle hundreds of watts of power. Point-contact transistors are limited to handling power outputs of somewhat less than one watt.

NOISE.—From the standpoint of noise, the junction transistor is far superior to the point-contact transistor. It should be noted that as new transistors are being developed, the noise figures for both types of transistors are improving steadily.

Basic Transistor Amplifier Circuits

Transistor amplifiers are divided into three classifications (as are vacuum-tube amplifiers). These are the grounded-base amplifier, the grounded-collector amplifier, and the grounded-emitter amplifier. (NOTE: The word ground, in nearly all its applications in electronics, should be considered in the general sense as being a reference point common to one or more circuits.) The terms common base, common emitter, and common collector are also widely used in identifying a particular type amplifier. Each of these will be discussed.

GROUNDED-BASE AMPLIFIERS.—Figure 8-17 (A) shows a grounded-base transistor amplifier; figure 8-17 (B) shows the equivalent vacuum-type amplifier.

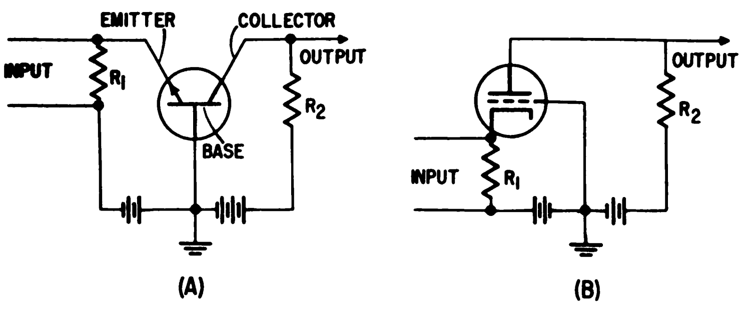


Figure 8-17.—(A) Grounded-base transistor amplifier; (B) grounded-grid vacuum-tube amplifier.

The grid of the vacuum tube is equivalent to the base of the transistor. If a positive-going signal is fed to the cathode of the tube, the output signal of the plate will possess the same polarity; that is, there will be no phase shift through the tube. The same thing is true in a grounded-base transistor amplifier. If the input signal across the emitter and base is positive, it will counteract some of the normal forward bias. This, in turn, will decrease the current flow from the emitter to the collector, causing the voltage drop across R_2 to decrease. This decrease causes the collector potential to become more positive. Thus, a positive-going signal on the emitter produces a positive-going output signal.

When the emitter input swings negative, the emitter bias will be increased more negatively than normal, causing an increase in current flow through the transistor, thus resulting in an increased voltage drop across R_2. This will make the collector potential more negative, and again the output polarity is the same as the input.

More power and voltage gains may be obtained from the grounded-base connection by using a junction transistor rather than a point contact. The gains obtained by using the junction transistor are around four times as great as may be obtained with the point contact.

The point-contact transistor is unstable in most circuit arrangements. This instability causes oscillations and erratic behavior. The grounded-base arrangement is most frequently used in point-contact transistors since it reduces the instability.

Grounded base type junction-transistor amplifiers are desirable from the standpoint of stability. However, better power gain can be obtained with a grounded-emitter type.

GROUNDED-EMITTER AMPLIFIER.—The most common arrangement for transistors that are used as amplifiers is the grounded emitter. In this arrangement the input signal is fed to the base and the output signal is taken from the collector. (See fig. 8-18 (A).) Figure 8-18 (B) shows an equivalent vacuum-tube amplifier. When a positive-going signal appears at the emitter, the emitter and base bias will increase, causing an increase of current flow through the transistor. Since the collector current has increased, the voltage drop across R_2 will also

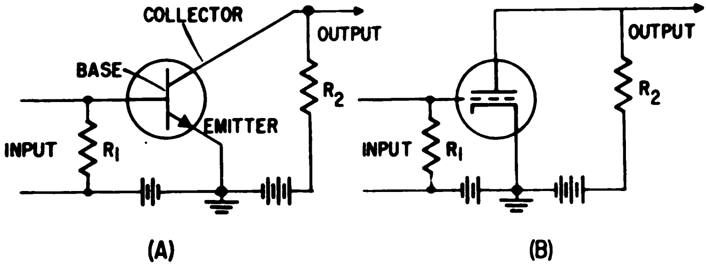


Figure 8-18.—(A) Grounded-emitter amplifier; (B) grounded-cathode amplifier.

increase, causing the collector voltage to be more negative. It can then be seen that in a grounded-emitter amplifier there is a phase shift through the transistor, just as there is in a vacuum-tube grounded-cathode amplifier.

When the input signal of the transistor swings negative, it tends to reduce the bias potential between the emitter and base. This causes a decrease in current flow through the transistor, causing the collector current to decrease and a decreased voltage drop across R_2. Since the voltage drop across R_2 has decreased, then the upper part of R_2 will be a more positive voltage. This action is true for both junction and point-contact transistors. The grounded-emitter arrangement is seldom used in point-contact transistor amplifiers because it produces a circuit that is inherently unstable; however, this arrangement is used in oscillator circuits that employ the point-contact transistor.

GROUNDED-COLLECTOR AMPLIFIER.—The grounded collector is the third arrangement and is shown in figure 8-19 (A); figure 8-19 (B) shows the equivalent vacuum-tube circuit.

The grounded-plate vacuum-tube amplifier is known as the cathode follower. The gain of the cathode follower is always less than one. This is also true in a grounded-collector arrangement since its gain is also less than one.

As in the cathode follower, there is also no phase reversal of the signal between input and output of the grounded collector. A useful characteristic of the grounded-collector circuit is its ability to conduct signals in either direction. It may be used as a two-way amplifier.

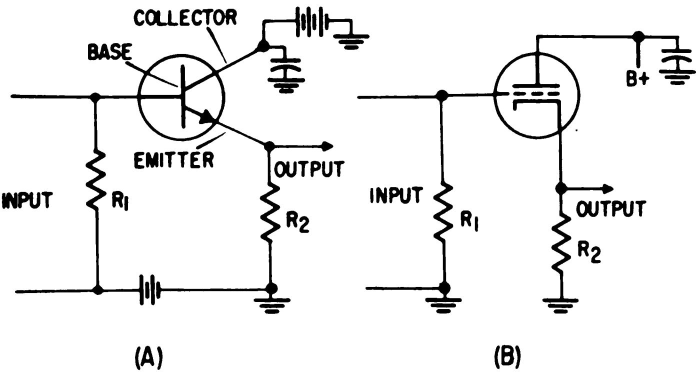


Figure 8-19.—(A) Grounded-collector transistor amplifier; (B) grounded-plate vacuum-tube amplifier.

CASCADED AMPLIFIERS.—Transistor amplifiers seldom use only one transistor. It is more common to find them connected (cascaded) in groups of two, three, or more stages.

Because of higher input and output impedances, vacuum tubes are easily connected in cascade. This is NOT true so far as transistors are concerned, because the input impedance is small compared to the output impedance. If the output of one transistor stage is connected directly to the input of another, there will be considerable loss in gain. Because of this mismatch between input and output impedances, more stages would be needed in order to obtain a given gain.

Special miniature transformers (stepdown transformers) have been the solution to this problem, but they do not have frequency response obtainable from R-C networks. Either the stepdown transformer or the R-C network may be used, depending on the application and the response desired.

As an Aviation Electrician you may be required to service transistorized equipment. New equipment that is being used in the fleet today contains transistorized circuits. As newer equipment is developed, more transistors will be used. A good understanding of basic transistor theory will aid you in maintaining these transistorized equipments. Transistors are now being used as

amplifiers in some fuel quantity systems and some autopilots. In the near future you can expect to find transistors being used as oscillators and phase inverters in some of your equipment. The special problems involved in maintaining and troubleshooting transistorized equipment is discussed in chapter 14 of this training course.

QUIZ

1. As compared to junction transistors, point-contact transistors have a
   a. higher power output
   b. lower voltage gain
   c. lower noise level
   d. larger collector contact area
2. The number of electrons entering into a single covalent bond in the crystal structure of germanium is
   a. 1
   b. 2
   c. 3
   d. 4
3. Current will flow through intrinsic germanium at room temperature due to
   a. thermal agitation
   b. skin effect
   c. covalent bonds
   d. low resistance paths in crystals
4. P-type germanium is formed by adding
   a. electrons
   b. donor impurity
   c. trivalent impurity
   d. arsenic
5. The barrier potential is determined by the
   a. current flow
   b. bias connection
   c. thickness of the barrier layer
   d. amount of impurities
6. Refer to figure 8-17. In the grounded-base amplifier when the emitter input swings negative, the
   a. emitter bias is reduced
   b. collector current decreases
   c. voltage across R_2 decreases
   d. collector potential swings negative

7. To neutralize the barrier potential of a *PN*-junction diode, a battery should be connected to deliver
   a. forward bias
   b. intrinsic ions
   c. reverse bias
   d. only covalent electrons
8. Point-contact diodes are usually used
   a. for low power applications
   b. as voltage amplifiers
   c. with very high current flows
   d. as power amplifiers

9. Germanium possesses four valence electrons; therefore it is classified as
   a. trivalent
   b. pentavalent
   c. tetravalent
   d. bivalent

10. A *PN* junction can be formed by
    a. fitting *P*-type and *N*-type crystals together
    b. the addition of holes to *P*-type germanium
    c. the addition of electrons to *N*-type silicon
    d. forming a single crystal with both *P*- and *N*-type characteristics
11. Refer to figure 8-14. Should 10 percent of the emitter electrons combine with the holes in the base and with the emitter-base resistance at 500 ohms and collector-base resistance at 500,000 ohms, the voltage gain would be
    a. 1,000
    b. 9,000
    c. 950
    d. 900
12. Using the same values as in question 11, the power gain would be
    a. 900
    b. 810
    c. 902.5
    d. 8,100

13. Refer to figure 8-19. This circuit is comparable to the vacuum tube cathode follower because it
    a. employes a 180° phase reversal
    b. has a gain of less than one
    c. has a constant emitter voltage
    d. requires no emitter bias

14. If an e.m.f. is impressed across a crystal of germanium, the electrons will
    a. move to the negative side
    b. move randomly
    c. not move
    d. move to the positive side

15. *N*-type germanium has a/an
    a. acceptor impurity
    b. donor impurity
    c. deficiency of electrons
    d. excess of holes

16. Refer to figure 8-18. This circuit is seldom used in point-contact transistors because it
    a. employs no phase shift
    b. produces an unstable circuit
    c. has a very low current gain
    d. has a gain of less than one

17. The transistor's ability to amplify lies in the fact that there is a difference in the
    a. direction of electron and hole motion
    b. emission, giving a current gain greater than one
    c. voltage and current gains
    d. low emitter-to-base resistance and high collector-to-base resistance

18. Refer to figure 8-14. If the applied signal goes negative, the
    a. emitter current increases
    b. drop across R_L decreases
    c. emitter-to-base resistance increases
    d. forward bias decreases

19. The potential barrier in a *PN* junction is formed when
    a. no e.m.f. is applied
    b. the connection is forward bias
    c. current flows
    d. the connection is reverse bias

20. Electrons can be removed from the outer ring of a silicon atom
    a. more easily than from a germanium atom
    b. as easily as from a germanium atom
    c. but with more difficulty than from a germanium atom
    d. without the application of power

CHAPTER 9

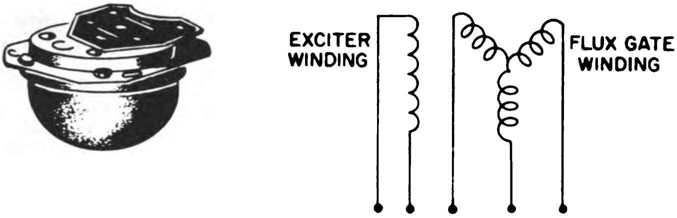
AIRCRAFT COMPASS SYSTEMS

Manufacturers have developed compass systems that are considerably more accurate than the older systems. These new systems are similar and their outstanding feature is the use of a more accurate directional gyro. These gyros possess a drift rate that is within the range of 2 to 4 degrees per hour as compared to the 12 degrees of earlier gyros. The overall accuracy requirement of military systems has been established as a maximum drift of less than 4 degrees per hour. The designation of MA-1 has been assigned to those military compass systems that meet the currently approved specification.

Lear and General Electric manufacturers are supplying compasses that meet the MA-1 specifications. Each company produces a compass system that achieves practically the same end result, but the methods and features utilized in the two systems differ slightly. This chapter will cover the features incorporated in a typical MA-1 compass. The electrical features of this system will be described in detail.

TRANSMITTERS

Basically, the transmitters used in the different (manufacturers) MA-1 compass systems are the same except for the nomenclature and appearance. Their theory of operation is the same. Figure 9-1 (A) shows a typical compass transmitter; figure 9-1 (B) is an internal schematic diagram of the transmitter.



(A) (B)

Figure 9-1.—(A) Typical compass transmitter; (B) schematic of compass transmitter.

The compass transmitter is an inductor type. It senses the magnetic heading of the aircraft and generates a corresponding signal. Since this transmitter is only a few inches in height, it can be installed within the wing or tail of the aircraft where magnetic disturbances are lowest. The compass transmitter consists of a hemispherical bowl which contains the sensing element. This element is mounted pendulously so that its average position in the horizontal component of the earth's magnetic field (the only component of any value for directional purposes) is normally maintained regardless of the turbulence of the air or the attitude (within limits) of the aircraft. To prevent excessive swinging of the functioning element while the aircraft is in flight, the hemispherical bowl is filled with damping fluid and the functioning element is weighted so that it can, within limitations, continually respond to the force of gravity.

The compensating screws, located on top of the transmitter, are used to eliminate most of the magnetic deviation caused by the aircraft electrical equipment and ferrous metal. One of the two compensating screws is lettered N-S for north and south deviation correction, the other E-W for east and west correction.

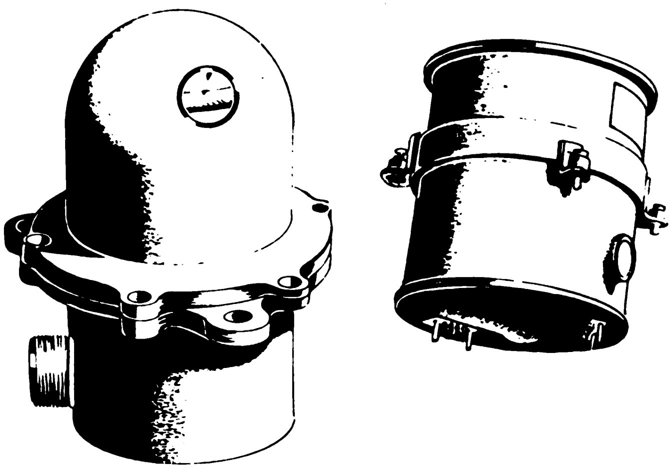
The correct procedure for adjusting the compensating screws to correct for deviation is given in the HMI for the aircraft. This information is also given in applicable military specifications. Operation of the compass element is similar to the operation of a synchro. The compass element consists of a rotor and stator (primary and secondary). The stator has 3 windings, spaced 120°

apart, connected in wye. It is mounted on the inside of the compass transmitter bowl. The rotor rests and turns on a jewel pivot within the stator windings. Movement of the rotor is caused by a bar magnet. This magnet alines itself to the earth's magnetic field at all times regardless of aircraft direction. Thus, as the aircraft turns, the stator moves about the rotor.

The rotor of the compass element is energized with an a-c source inducing a voltage into the stator. The voltages induced in the stator windings are different from each other. Therefore, the resultant output of all three legs is different for any one magnetic heading. This resultant voltage is used to supply azimuth heading information to a directional gyro.

DIRECTIONAL GYRO UNIT

Every MA-1 compass system employs a directional gyro unit. These directional gyro units are basically the same. Figure 9-2 shows two directional gyro units. Their functions are the same, but they are used in two different MA-1 compass systems.



(A) (B)

Figure 9-2.—Directional gyro units.

The directional gyro shown in figure 9-2 (A) is a separate unit; the gyro shown in figure 9-2 (B) is inserted

inside an amplifier unit. The inside appearance of both directional gyro units is basically the same. The directional gyro shown in figure 9-2 (A) will be discussed. It consists of a gyro motor mounted in a gimbal suspension, together with torque motors for slaving and leveling, and pickoffs to provide signals containing leveling and azimuth information. The gimbal suspension consists of an inner and an outer gimbal arranged so that the gyro has three independent axes of rotation. The motor is a synchronous hysteresis type and operates at a speed of 24,000 r.p.m.

A cutaway view of the complete gyro is shown in figure 9-3. The electrical schematic of the gyro unit is shown in figure 9-4. The complete gyro is hermetically sealed in inert gas at a pressure of one atmosphere.

Slaving Torque Motor

The slaving torque motor (1, fig. 9-3) consists of two sets of coils mounted on the outer gimbal (2) and two disk-shaped permanent magnets (3) mounted on the inner gimbal. When the coils are energized by a direct current, their magnetic fields react with the fields of the magnets on the inner gimbal to produce a torque about the horizontal axis. This torque precesses the gyro about the vertical axis. The direction of precession is dependent upon the polarity of the direct current applied to the coils. Electric connections between the inner and outer gimbals are made through low torque spiral hairsprings (brushes) (4).

The slaving torque motor receives current from either the fluxvalve transmitter or latitude error signal controller. It can receive current from both at the same time. The total amount of current to the torquing motor is the sum of these two currents and determines the direction and amount of precession of the gyro motor.

Leveling Torque Motor

The leveling torque motor (5, fig. 9-3) consists of a two-phase stator mounted on the case frame and a hysteresis rotor mounted on the outer gimbal. The excitation winding of the stator is energized at all times with 115-volt, 400-cycle, single-phase power. The 400-cycle,

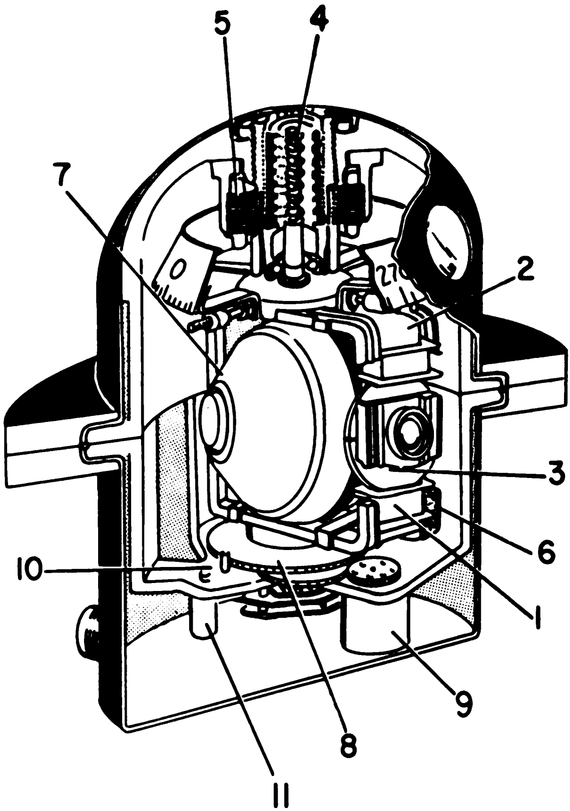


Figure 9-3.—Cutaway view of a directional gyro unit.

1. Slaving torque motor coil.
2. Outer gimbal.
3. Magnet.
4. Brushes.
5. Leveling torque motor.
6. Leveling pickoff coil.
7. Gyro motor.
8. Gear.
9. Synchro transmitter.
10. Antispin assembly.
11. Antispin motor.

single-phase voltage to the control winding is derived from the leveling amplifier output. This voltage varies from 0 to 26 volts, depending upon the amount of leveling required, and will shift in phase 180°, depending on the direction of leveling required. When the control winding is

energized, a torque is exerted about the vertical axis, causing the gyro to precess about the horizontal axis.

Leveling Pickoff

The leveling pickoff is taken from two coils (6, fig. 9-3) mounted on the outer gimbal. These coils are linked by the stray magnetic flux from the stator of the gyro motor (7). The induced voltage in these coils is minimum when the gyro motor is centered in the gimbals. When the spin axis of the gyro tilts about the horizontal axis, an a-c voltage is induced into the pickoff coils. The magnitude of the induced voltage is proportional to the amount of tilt.

Azimuth Information

A large gear (8, fig. 9-3) at the bottom of the gyro's outer gimbal is coupled to the rotor of the synchro transmitter (9) which provides an electrical output signal. The output signal is a function of the position of the gyro in azimuth. The following description of signal paths refers to figure 9-7.

The signals from the gyro synchro transmitter *S*5 are fed through a synchro differential *S*4 and a synchro control transformer *S*1 in the amplifier unit, and then to the servo amplifier. The output signals from the servo amplifier drive a servomotor that positions the rotors of synchros *S*1, *S*2, and *S*3. These rotors are mechanically coupled to the servo shaft. The output of *S*3, in turn, provides azimuth information suitable for use in such equipment as autopilots and radio navigation equipment.

Antispin Motor

An antispin assembly (10, fig. 9-3) is employed in the gyro unit to prevent excessive spinning of the outer gimbal when the system is turned off.

The antispin assembly consists of a spring-loaded pin that presses against the edge of a gear on the outer gimbal. Ten seconds after the gyro is energized, the antispin motor (11) moves the pin away from the gear so that the outer gimbal is free to rotate. When the gyro is deenergized, the pin immediately moves against the gear, applying a braking action to the outer gimbal.

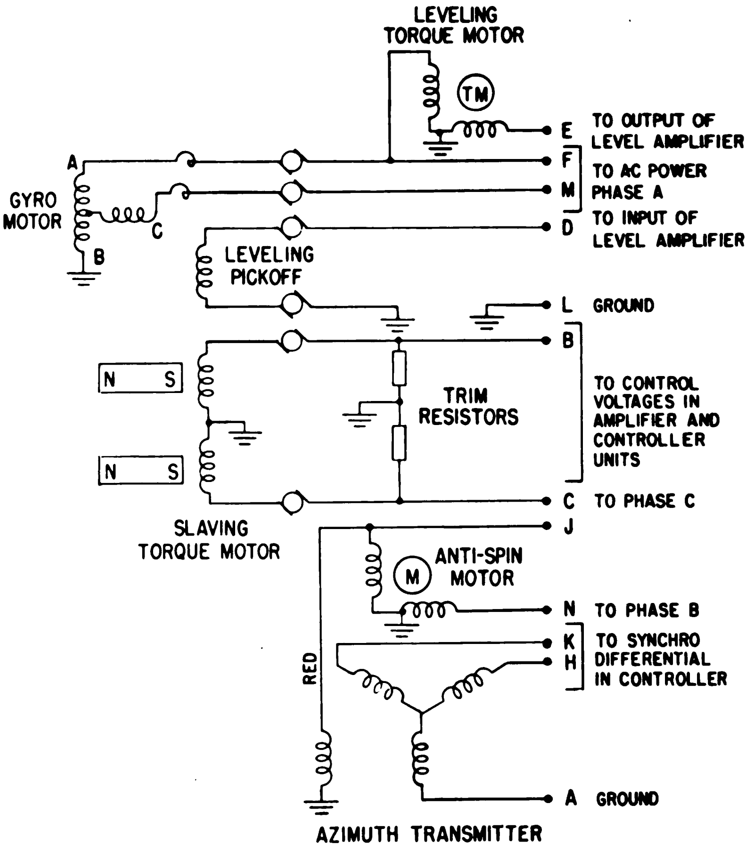


Figure 9-4.—Circuit diagram of directional gyro unit.

Electrical Connections

Electrical connections for the gyro motor, the slaving torque motor, and the leveling pickoffs are made through brushes and sliprings at the top of the outer gimbal.

MA-1 COMPASS CONTROLLER

The controls for synchronizing the compass system, for selecting mode of operation, and for setting in latitude are contained in a single cockpit control unit. Figure 9-5

shows two typical controller units; figure 9-6 is an internal schematic of the controller shown in figure 9-5 (B).

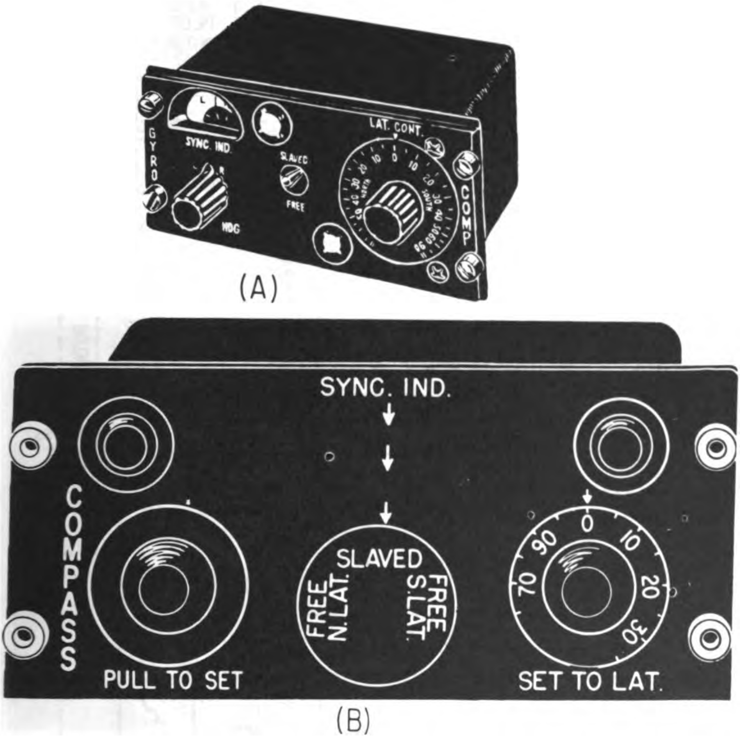


Figure 9-5.—(A) Lear MA-1 controller; (B) General Electric MA-1 controller.

The two controllers shown in figure 9-5 are identical in operation but differ slightly in appearance. For purpose of explanation, the General Electric controller will be described.

Synchronizing Procedure

The heading set knob, labeled PULL TO SET (fig. 9-6) permits rotation of a synchro differential rotor. This synchro is connected, as shown in figure 9-7, between *S*5 (the output synchro of the gyro) and *S*1 (a synchro control transformer in the amplifier). This arrangement makes it possible to change the position of the servo shaft without actually moving the gyro's axis.

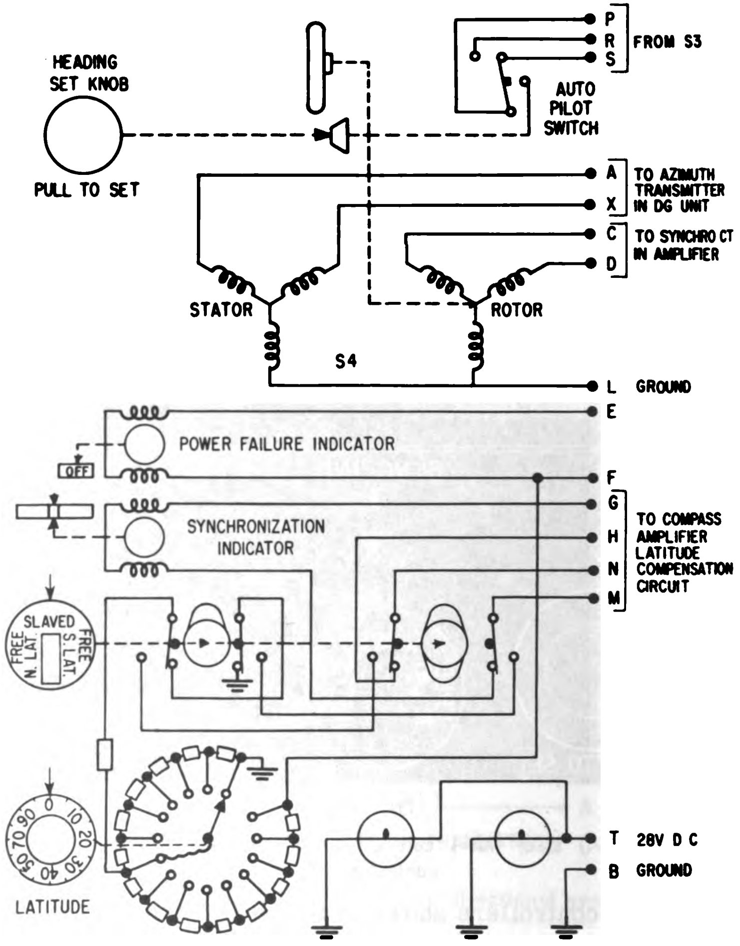


Figure 9-6.—Circuit diagram of the General Electric controller.

In order to understand the importance and need for a synchro differential, it is necessary to analyze what happens after the compass system is turned on. Assume that the gyro is up to speed and its axis is as shown in the right-hand section of figure 9-7. Also assume that the fluxvalve compass is delivering directional information as shown at S2 in the left-hand section of the figure.

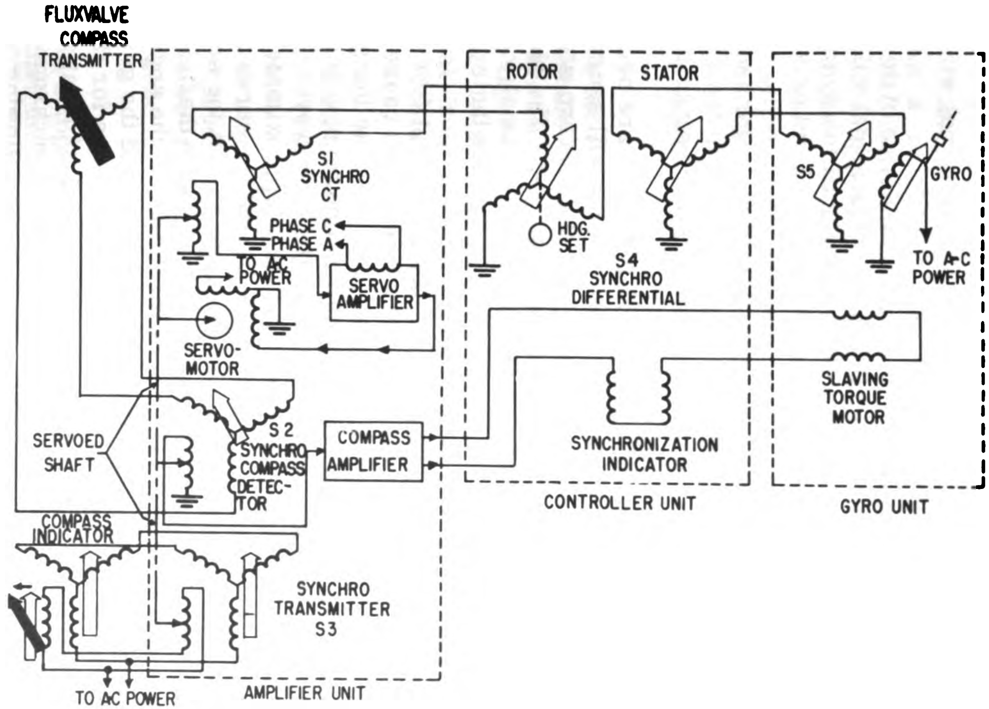


Figure 9-7.—Diagram showing the effects of the synchro differential.

Beginning with these conditions, the following events will occur:

1. As soon as power is applied, the rotor of synchro *S*1 (control transformer) will deliver a signal to the servo amplifier due to the angular difference between the stator field and rotor. The magnitude of this signal will be proportional to the angular error.

2. Depending upon the phase characteristics of the input signal to the servo amplifier, the output signal will be such that it will drive the servomotor until the synchro CT's rotor is alined with the direction of the existing field in the CT's stator.

3. Since the synchro compass detector's rotor and the synchro transmitter's rotor are connected to the same servo shaft, they too will assume the same directional position as the synchro CT's rotor.

4. At the same time that events 1, 2, and 3 are occurring, the synchro compass detector's rotor will sense an angular difference between itself and the synchro stator and feed a signal into the compass amplifier. The phase and magnitude of this signal will be proportional to the size and direction of the angular error between the stator and rotor.

5. The output signal from the compass amplifier will drive the slaving torque motor in a direction to cause the gyro's axis to precess in an attempt to aline the gyro synchro *S*5 with the directional information being received from the fluxvalve compass transmitter. However, this precession will take place at a rate of approximately 2 degrees per minute. The synchro CT and the servo amplifier, on the other hand, are designed so that the servo shaft will position itself almost instantly when the field of the synchro stator *S*1 changes direction. If the angular difference between the fluxvalve compass and the gyro's axis were 90°, it would obviously take 45 minutes for them to synchronize. The synchro differential *S*4 located in the controller unit is used to reduce this synchronizing time to a few seconds. This is done in the following way:

The heading set knob, as shown in figure 9-7, which is mechanically connected to the synchro differential's rotor *S*4, is rotated to position the rotor so that the direction of the field produced in the synchro CT's stator *S*1 is identical to that of the fluxvalve compass. Therefore,

all of the synchro rotors attached to the servo shaft will immediately assume a position identical to that of the fluxvalve compass. This directional information will also cause the stator of the output synchro transmitter S3 to position the compass indicator to the magnetic heading of the aircraft.

As a result of changing the rotor's position in the synchro differential, the rotor of the synchro compass detector is positioned so that it is practically alined in the same direction as the stator field. Thus, the signal being fed into the compass amplifier is extremely small. The output signal of the compass amplifier is also very small. However, this small remaining signal is sufficient to precess the gyro until the rotor and stator field of S2 are completely alined.

Synchronization Indicator

To facilitate synchronizing the MA-1 compass system by means of the synchro differential, a SYNC indicator (a zero center milliammeter) is installed in the controller. (See fig. 9-5.) When the vertical white marker in the indicator is approximately centered, it shows that the output signal from the compass amplifier is near null and that synchronization exists between the fluxvalve compass and gyro.

After synchronization is achieved, the gyro will then be slaved to the fluxvalve compass and its axis will precess in response to any average directional changes in the fluxvalve compass. Since the gyro, when slaved, precesses at such a slow rate (2 degrees per minute), it does not respond to the continuous rapid fluctuations of the fluxvalve compass, but only to the average direction changes.

Autopilot Switch

An autopilot switch is connected to the heading set knob so that the switch operates when the knob is pulled out. This switch can be used to cut out the autopilot when the system heading is being changed. It is used only when signals from S3, the servo output synchro of the system, are used for autopilot operation (fig. 9-6).

The mode of operation selector switch, labeled FREE N LAT-FREE S LAT (fig. 9-6), selects either compass

controlled (slaved) or free gyro operation. There are two switch positions for free gyro operation—one for northern latitudes, and one for southern latitudes.

Latitude Compensation

The latitude compensation control is located at the right-hand side of the controller unit. One is labeled SET TO LAT and the other LAT CONT (fig. 9-5). This control sets the amount of compensation voltage required for canceling the apparent drift due to the earth's rotation. This compensation voltage, which is used only when the system is set for free gyro operation, provides a direct current to the coils of the slaving torque motor of the gyro. This current precesses the gyro at a rate equal and opposite to the apparent drift due to the earth's rotation.

Power Failure Indicator

A power failure indicator that indicates when power to the system is turned off or has failed is visible through the synchronization indicator window. This indicator incorporates a red flag labeled OFF that is visible through the window in the front panel of the controller.

MA-1 COMPASS AMPLIFIER

The amplifiers used in the different MA-1 compass systems vary in shape and size. This is illustrated in figure 9-8. The amplifier shown in part (A) is used in the Lear MA-1 compass system; the one shown in part (B) is used in the General Electric MA-1 compass system. The amplifier used in the General Electric system will be used for purposes of explanation.

The amplifier contains a servo unit, a servo amplifier unit, a compass amplifier unit, and a leveling amplifier unit. The servo unit and the compass amplifier are plug-in units. The amplifier also serves as a junction box and power supply for the complete system. A block diagram of the system is shown in figure 9-9.

The input to the servo amplifier unit is the rotor voltage of the synchro control transformer in the servo unit.

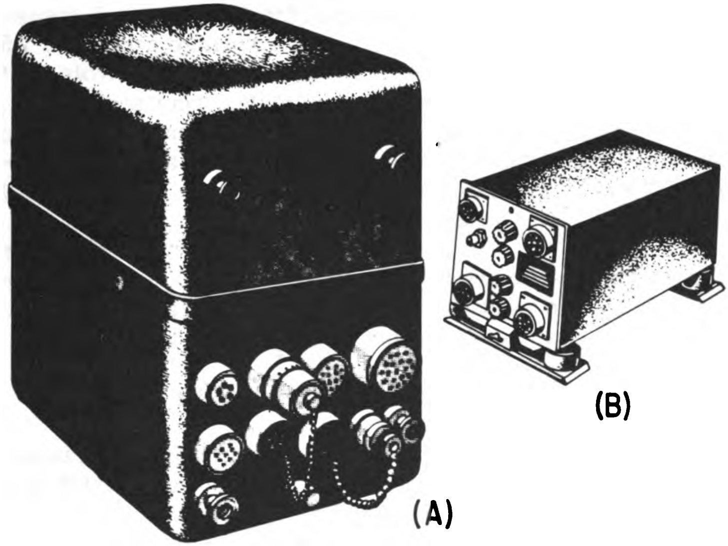


Figure 9-8.—(A) Lear amplifier; (B) General Electric amplifier.

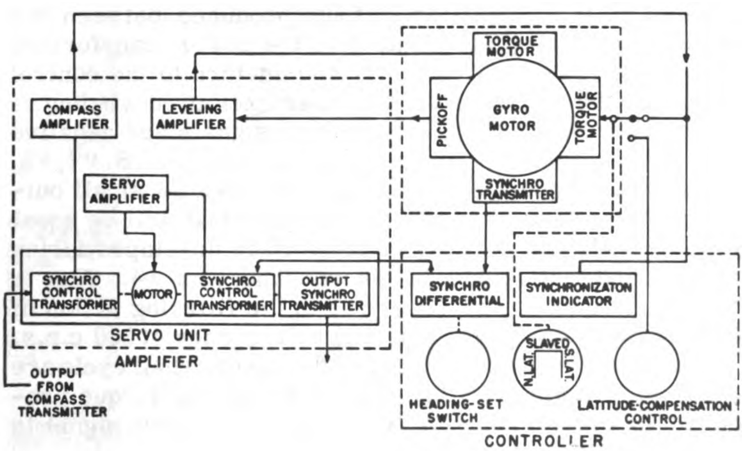


Figure 9-9.—Block diagram of amplifier, controller, and gyro unit connected as a system.

(See fig. 9-10.) The output signal from the control transformer passes through single stage voltage amplifier *V*5 to a discriminator stage (*V*1, *V*2, *V*3, and *V*4). Note that resistors *R*1, *R*4, and *R*5 in the cathode circuits of *V*1, *V*2, *V*3, *V*4, and *V*5 are not bypassed. This feature tends to maintain the output signals from the servo amplifier relatively uniform in magnitude, regardless of the size of the error input signals.

Since *V*1, *V*2, *V*3, and *V*4 become saturated when the error signals become greater than 1°, the torque delivered by the servomotor for error signals of 1° would be almost exactly the same as for strong error signals.

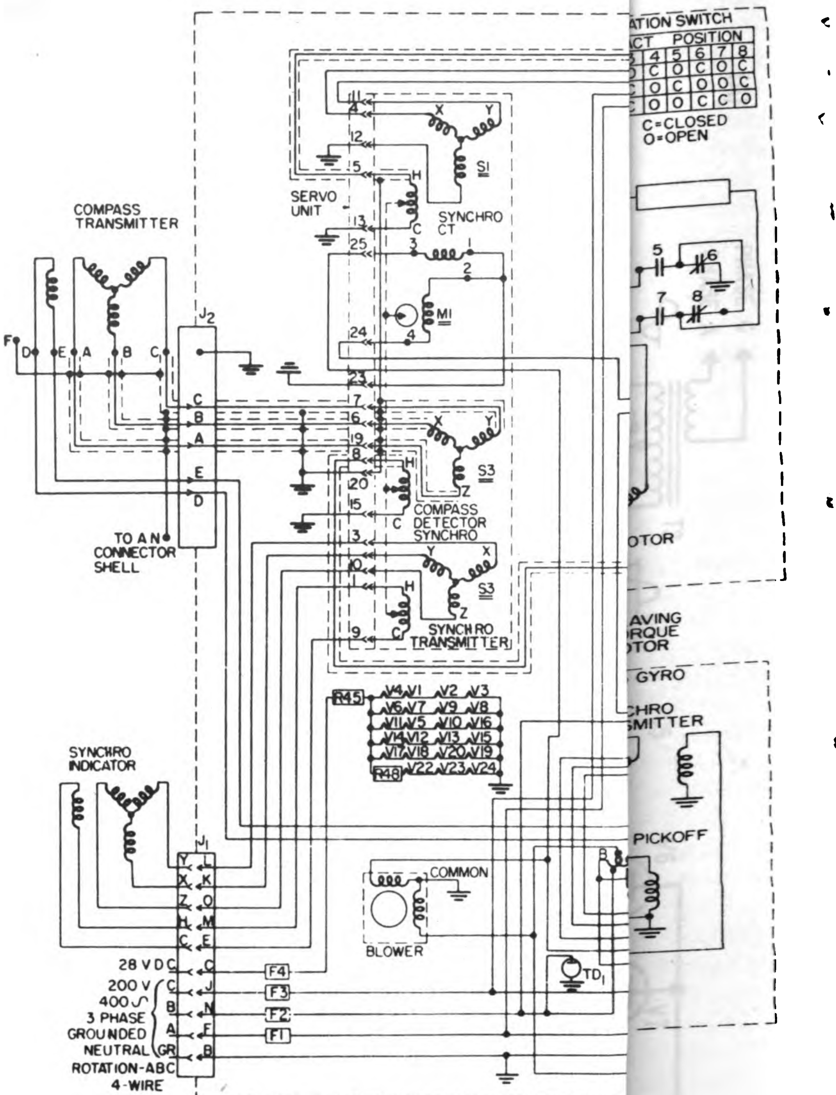
Phase Discriminator Operation

When no signal is applied to the discriminator circuit (fig. 9-11), tubes *V*1 and *V*2 will conduct alternately and thus develop a small voltage across *R*6. Likewise, *V*3 and *V*4 will develop a voltage across *R*7. The d-c voltages across *R*6 and *R*7 are fed through a filtering and stabilizing network to the grids of the output tubes *V*6, *V*7, *V*8, and *V*9.

The plates of the output tubes are excited 180° out of phase by a 400-cycle voltage from the phase A transformer. The amplifier output, produced between the center tap of the plate winding on the power transformer and ground, is applied to *T*4 and in turn to the control phase of the servomotor *M*1 whose excitation winding is powered by phase C. Since the grid signals are negative and of the same magnitude, power amplifiers *V*6, *V*7, *V*8, and *V*9 will conduct equally, and thus develop a small output voltage during the first half cycle that will be equal in magnitude and polarity to the voltage developed during the second half cycle in the secondary of *T*4. This is shown in figure 9-11 (D). Due to the filtering action of *C*4, the resultant waveshape has a frequency of 800 c.p.s.

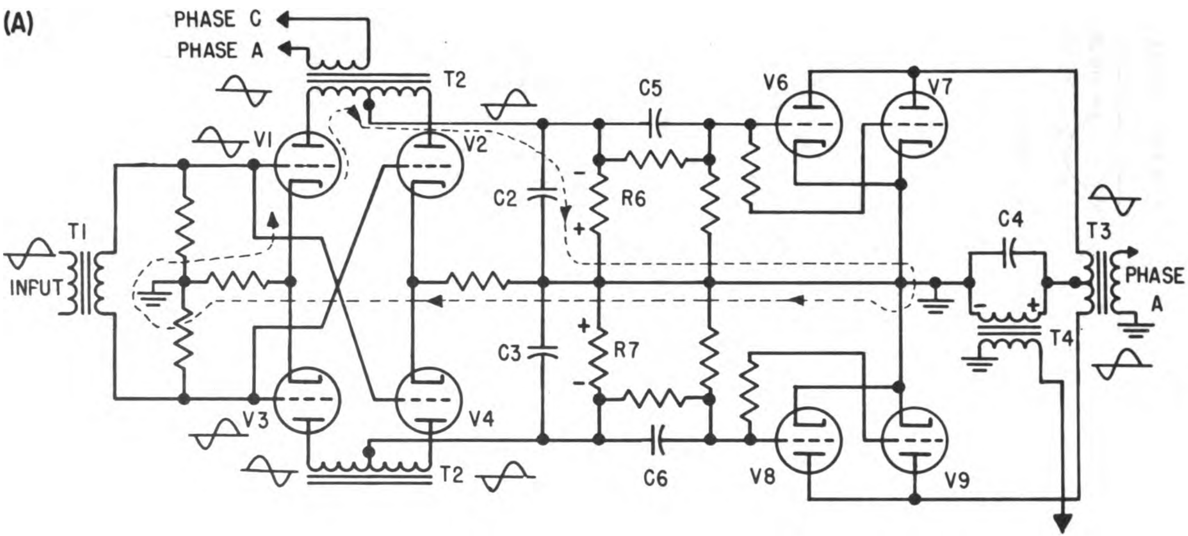
Since the voltages developed during each half cycle are equal in magnitude, there will be no turning torque produced in the servomotor when this 800-cycle signal is applied to its control winding.

Referring again to figure 9-11, assume that the output signal from *T*1 is fed to the grids of *V*1 and *V*3 with the phase polarity as shown, and that the line-to-line



COMPASS TRANSMITTER
TO A N CONNECTOR SHELL
SERVO UNIT
SYNCHRO CT
COMPASS DETECTOR SYNCHRO
SYNCHRO TRANSMITTER
SYNCHRO INDICATOR
BLOWER
COMMON
28 V D C
200 V 400 ∿ 3 PHASE GROUNDED NEUTRAL ROTATION-ABC 4-WIRE
C=CLOSED
O=OPEN
PICKOFF
OTOR

(A)



NOTE: THE WINDING CONNECTED TO THE PLATES OF V3 AND V4 IS ON THE SAME CORE AS THE WINDING CONNECTED TO THE PLATES OF V1 AND V2.

OUTPUT TO CONTROL PHASE OF SERVO MOTOR

Figure 9-11.—Phase discriminator in servo amplifier unit.

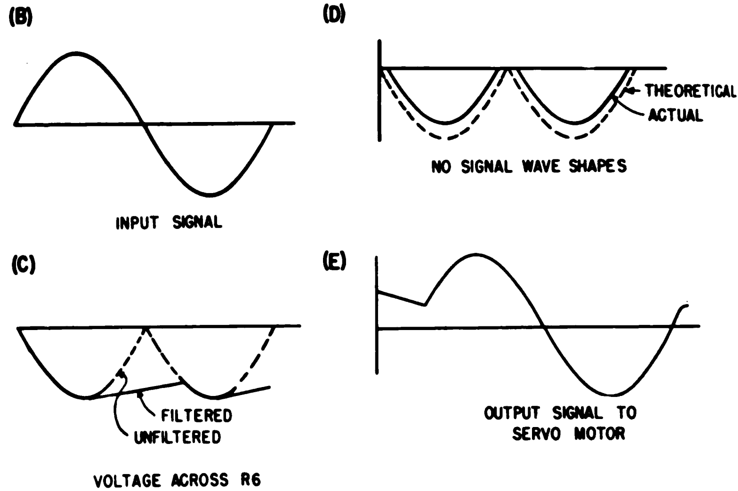


Figure 9-11.—Phase discriminator in servo amplifier unit.—Continued

reference voltage taken from phase A to phase C induces a voltage in the secondary and tertiary windings of $T2$ as shown. During the first half cycle of signal voltage, the only tube whose grid and plate are both going positive simultaneously is $V1$. Therefore, $V1$ will conduct, and a relatively large voltage will be developed across $R6$ as shown by the dashed waveform in figure 9-11 (C). During the second half cycle, the grid and plate of $V2$ will go positive simultaneously, thus causing this tube to conduct. Again a voltage will be developed across $R6$ with the same polarity as the previous pulse. The resultant output signal will resemble that of a full-wave rectifier. Capacitor $C2$ will smooth out this d-c voltage as shown by the solid line in figure 9-11 (C).

Referring to tubes $V3$ and $V4$, you can see that when the plate of $V3$ is positive the input signal on its grid is negative and therefore conducts less than during no-signal conditions. Likewise, $V4$ will conduct less during the second half cycle. Therefore, the d-c signal developed across $R7$ will be less than during no-signal conditions, and thus the input signal to $V8$ and $V9$ will be less negative.

Assume that the secondary voltage of power transformer $T3$, phase A, is as shown in figure 9-11 (A). Since the input d-c signal to tubes $V6$ and $V7$ is very

negative, they will conduct less than during no-signal conditions. On the other hand *V*8 and *V*9 will conduct more heavily whenever their plates are positive, which in this case is during the second half cycle. The output signal shown in figure 9-11 (E) has a large 400-cycle component in the second half cycle while the first half cycle has only a small 400-cycle component and a large 800-cycle component. The strong 400-cycle component in the second half cycle will produce a turning torque in the two-phase servomotor. This torque will cause the servo shaft to rotate in a direction which will reduce the input signal to the servo amplifier to zero. The signal is reduced to zero by positioning the synchro control transformer to electrical zero.

If the initial error signal had been of the opposite phase, the polarity of the signal at *T*1 would be exactly reversed (180° out of phase). As a result, the output signal from *T*4 would have a large 400-cycle component during the first half cycle rather than during the second half cycle, as in the case previously described. Hence the servomotor would rotate in the opposite direction, as is characteristic of two-phase motors.

Compass Amplifier

The overall operation of the compass amplifier will first be described to present a general understanding of the circuit. A detailed description of each circuit will follow.

The input to the compass amplifier is the rotor voltage of the compass detector synchro *S*2, as may be seen in figure 9-10. This signal is amplified in a two-stage voltage amplifier (*V*10 and *V*11). Since the frequency of the output signal from the fluxvalve compass transmitter and hence the input signal to *V*10 is 800 cycles, it is necessary that the frequency of the voltage applied to the plates of *V*12 and *V*13 also be 800 cycles for proper discriminator action. The d-c output of the discriminator is amplified in a push-pull d-c amplifier (*V*14 and *V*15) and is further amplified in a push-pull magnetic amplifier. The output from the magnetic amplifier is a direct current that is proportional in magnitude to the 800-cycle a-c input signal, and the polarity depends on the phase of the input signal.

This output signal from the compass amplifier unit is fed to the slaving torque motor in the gyro unit. Referring to figure 9-7, it can be seen that the SYNC indicator is in series with one of the output leads from the compass amplifier. As mentioned previously, when the vertical white marker in the indicator is approximately centered, it shows that the output signal from the compass amplifier is near null and that synchronization exists between the fluxvalve compass and gyro. Any error signals developed by *S*2 will cause the gyro to start precessing in a direction that will null the error signal at the slow rate of approximately 2 degrees per minute.

The output voltage from the magnetic amplifier *T*8 and *T*9 will be approximately constant regardless of the magnitude of the error signal. This is also true of the output from the servo amplifier. As in the servo amplifier, this characteristic is achieved in the compass amplifier by incorporating a large amount of degenerative feedback. This occurs because the cathodes of *V*11, *V*12, *V*13, *V*14, and *V*15 are not bypassed with capacitors.

Frequency Doubler Operation

Referring to figure 9-12, assume that the windings connected to the diodes (rectifier) do not exist. If this were the case, *T*6 and *T*7 would act simply like a transformer and produce two 400-cycle sinusoidal output voltages *E*1 and *E*2, which would cause currents *I*1 and *I*2 to flow in the direction represented by the arrows. However, note that the sum of *E*1 and *E*2 would produce a zero output voltage since they are equal in magnitude and are opposing.

If the diode windings are considered to be in the circuit, the lower diode will conduct during the first half cycle and the upper diode during the second half cycle.

The impedance of these diode circuits is high when there is no conduction, and drops to a low value of approximately 75 ohms when conduction occurs. As in a conventional transformer, when the secondary impedance is low, the impedance reflected into the primary is also low. Again, referring to figure 9-12, it can be seen that when *I*4 flows, the impedance of *T*7's primary is low, thus causing most of the input voltage to appear across *T*6's

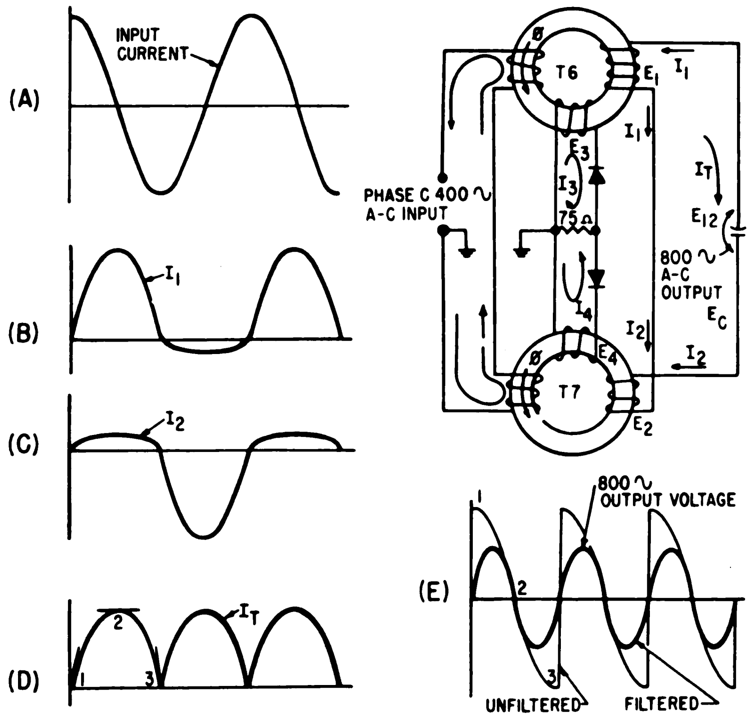


Figure 9-12.—Schematic of frequency multiplier which supplies an 800-cycle voltage to the compass amplifier.

primary. For this reason, *I*1 will be large and *I*2 quite small during the first half cycle, as shown in figure 9-12 (B) and (C). Likewise, during the second half cycle, the other diode will conduct which will cause *I*2 to be large and *I*1 small. The sum of these two currents, I_T, which flows through *C*12 is shown in figure 9-12 (D).

The voltage across *C*12 is proportional to the rate of change of flux in *T*6 and *T*7. This change is approximately equal to the rate of change of the current.

Referring to the current waveshape in figure 9-12 (D), it may be seen that the slope at point 1 is maximum in a positive direction. Therefore, the voltage is maximum at point 1 as can be seen in figure 9-12 (E). At point 2 the slope is zero. At point 3 the slope is maximum in the negative direction. The voltages corresponding to points

1, 2, and 3 are shown by the heavy sine wave in figure 9-12 (E). The unfiltered voltage, which is the result of the 800-cycle output of *E*1 and *E*2, is shown by the light line in figure 9-12 (E). This is a theoretical voltage. After being filtered by *C*12, this voltage will appear in the near half-sinusoidal form as shown by the heavy line in figure 9-12 (E).

Discriminator Operation

The plate voltages supplied to *V*12 and *V*13 are 800-cycle reference voltages which are exactly in phase, as may be seen in figure 9-13. The 800-cycle input signals to these tubes, on the other hand, are 180° out of phase, as shown. With no signal applied, *V*12 and *V*13 will conduct equally when their plates swing positive, and will develop equal voltages across *R*23 and *R*25. Thus, the grids of *V*14 and *V*15 will have equal voltage on them, and will conduct equally.

Assume that an error signal fed into *V*10 is such that the output voltage developed across the secondary of *T*5 is as shown in the figure. During the first half cycle, *V*12 will conduct heavily, developing a large voltage across *R*23 since *V*12's grid and plate are both positive simultaneously. During the second half cycle, it will not conduct at all.

During the first half cycle, *V*13 will barely conduct since its grid is negative while its plate is positive. Thus, the voltage developed across *R*25 will be less than during no-signal conditions. During the second half cycle, neither *V*12 nor *V*13 conducts since their plates are negative.

The sum of the voltages across *R*23 and *R*25 is applied across *R*24 and *R*26 (fig. 9-13), where it is initially divided equally and filtered. Therefore, a negative voltage will be applied to *V*14, cutting off its conduction. A positive voltage is applied to *V*15 which will make it conduct heavily. When this happens, the low value of cathode and tube resistance across *R*26 reduces the signal voltage across *R*26. This causes most of the signal voltage developed across *R*23 and *R*25 to appear across *R*24. This characteristic increases the amount of control action of the output circuit.

Had the input error signal been 180° out of phase, *V*15 would then be cut off and *V*14 would conduct heavily.

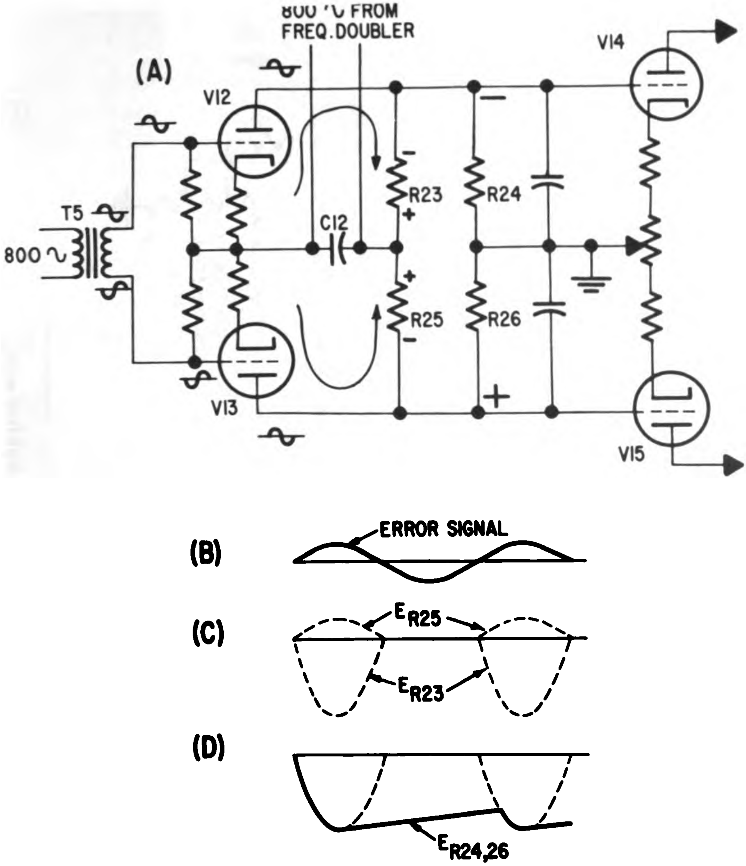


Figure 9-13.—Discriminator section of compass amplifier unit.

Magnetic Amplifier Operation

The basic amplifier symbols used in the description of this circuit are shown in figure 9-14 (B). Load windings are generally labeled *A*1 to *A*2 and *B*1 to *B*2; while control or bias windings are labeled *F*1 to *F*2, *F*3, to *F*4, *F*5 to *F*6, and so forth. Assuming the electron flow is represented by *I* 1, *I* 2, and *I*3, fluxes will be set up in the directions represented by the large arrows adjacent to the windings shown in the figure.

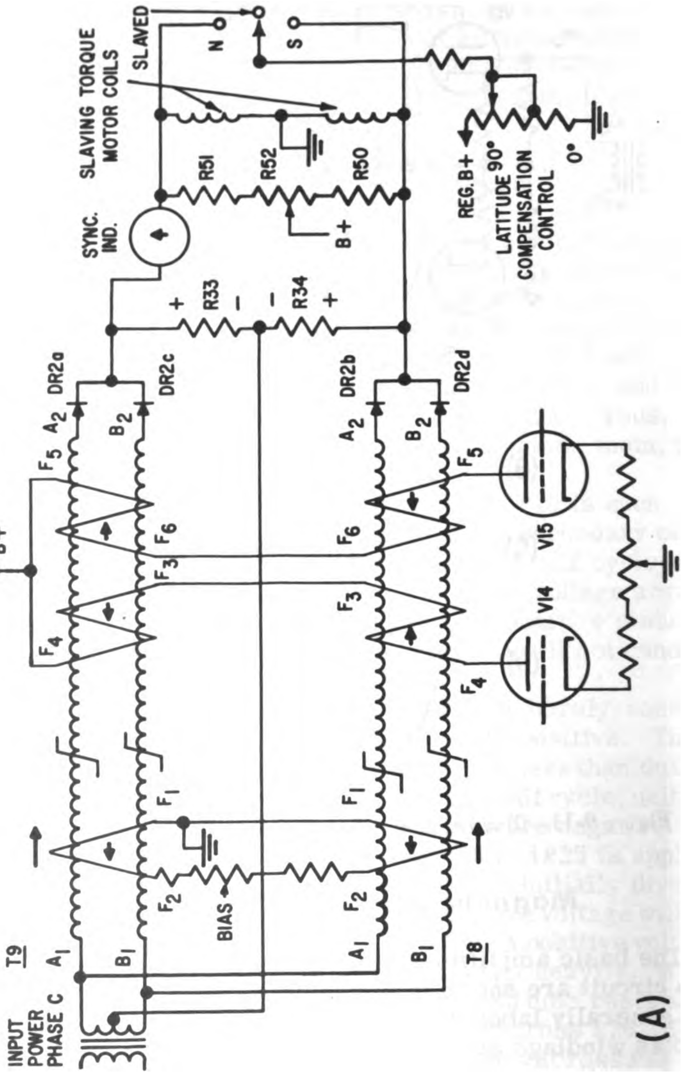


Figure 9-14.—Magnetic amplifier in compass amplifier unit.

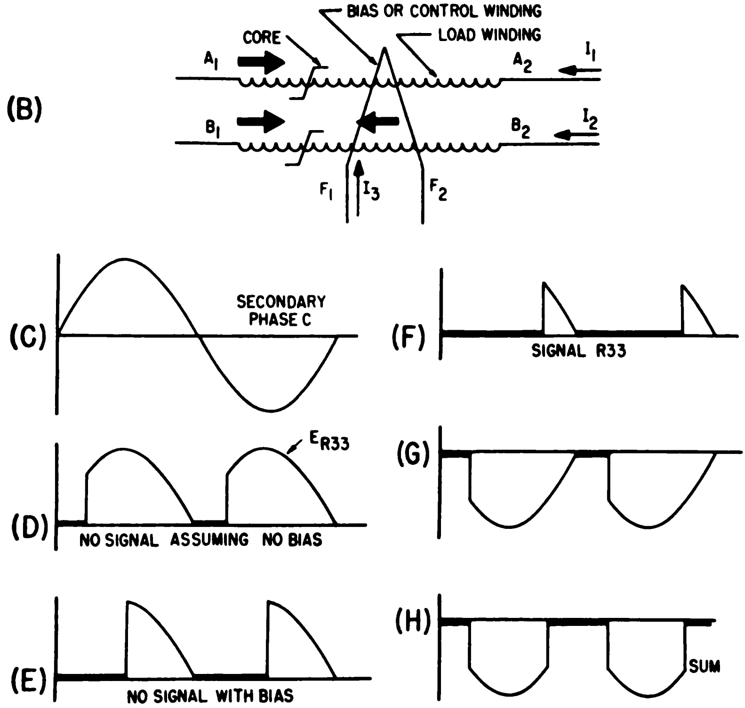


Figure 9-14.—Magnetic amplifier in compass amplifier unit.—Continued

The operation of the magnetic amplifier may be understood better by referring to figure 9-14 (A). The four cores comprising *T*8 and *T*9 are all magnetically independent, although controlled by common windings from *V*14, *V*15, and the bias circuit.

During no-signal conditions, *V*14 and *V*15 would conduct equally. Thus, control windings *F*3 to *F*4 and *F*6 to *F*5 would produce equal and opposite fluxes, which would cancel each other in *T*8 and *T*9. This is shown by the arrows in figure 9-14 (A). Hence, their overall effect on these cores is negligible.

The action of the load windings is as follows:

Assume that an a-c voltage with the polarity shown (fig. 9-14 (C)) exists on the secondary of phase C. Diodes *DR*2a and *DR*2b would conduct during the first half cycle

and produce flux in the *A*1 to *A*2 load windings in the directions represented by the large arrows.

When *T*8 and *T*9 are not saturated, their impedances are high, and thus most of the voltage from phase C's secondary is dropped across the load coils in *T*8 and/or *T*9. There is very little voltage across *R*33 and *R*34. However, as soon as *T*8 and/or *T*9 saturate, the impedance of the coils drops to a very low value and most of the voltage appears across *R*33 or *R*34, respectively. In a sense, this characteristic is similar to thyratron action.

If no bias current is flowing, the current flowing through *DR*2a will cause *T*9 to saturate early in the first half cycle, and thus produce a voltage waveform across *R*33. (See fig. 9-14 (D).) Considering the effect of bias current, notice that the flux produced by the bias circuit opposes the flux described, and thus tends to retard or delay the saturation of *T*9. Therefore, most of the input voltage appears across *R*33 later in the first half cycle. This is shown in figure 9-14 (E). *DR*2a and *DR*2c conduct alternately and thus produce a full-wave output across *R*33, as may be seen in figure 9-14 (E).

The voltage waveshape across *R*34 is exactly the same as across *R*33. However, the polarity of the voltage is exactly opposite, so that during no-signal conditions these voltages cancel each other. Assume that a signal causes *V*14 to conduct heavily and *V*15 only slightly. The flux produced in *T*9 by control winding *F*3 to *F*4 will oppose the load winding flux represented by the large arrow and thus further retard the saturation of *T*9. (See fig. 9-14 (F).) However, the flux produced in *T*8 by current flow through *V*14 aids the flux produced by the current through *DR*2b and *DR*2d. Therefore, the time of saturation will be advanced, and the resultant voltage across *R*34 will be as shown in figure 9-14 (G).

The sum of the voltages across *R*33 and *R*34, shown in figure 9-14 (H), is a d-c voltage which is applied to the slaving torque motor coils. Had the input error signal been in the opposite direction and of the same magnitude, the output voltage waveshape would be the same as shown in figure 9-14 (H), but with the opposite polarity.

During no-signal conditions, very small equal and opposite currents flow through the slaving torque motor coils, due to the B voltage applied to the coils through *R*50, *R*51

and *R*52 (fig. 9-14 (B)). When an error signal exists and a d-c voltage is produced across *R*33 and *R*34, as already described, a current flows through both torque motor coils from the magnetic amplifier. This current aids the B+ voltage in one coil and bucks the B+ voltage in the other. This causes the slaving torque motor to rotate which, in turn, makes the gyro precess in azimuth in such a direction to cancel the original error signal.

When the MA-1 is being utilized without compass slaving, a small latitude compensation voltage is fed to either the right or left torque motor coil. The coil to which it is fed depends upon whether the MA-1 is in the north or the south latitude. This is illustrated by the switch shown in the slaved position in figure 9-14 (B).

Leveling Amplifier Operation

The leveling amplifier consists of one voltage amplifier stage (*V*16) and a four-tube power amplifier stage (*V*17, *V*18, *V*19, and *V*20). (See fig. 9-15.) Its function is to amplify signals from the leveling pickoff of the gyro to an amount suitable for operating the leveling torque motor.

Assume that the phase relationship of the leveling pickoff voltage applied to the grid of *V*16 is as shown in (A) of figure 9-15. The relation of this voltage to phase A voltage is shown at (B) and (C). *V*17 and *V*18 will conduct heavily during the first half cycle, and *V*19 and *V*20 during the second half cycle. This is conventional push-pull amplifier action. With the signal as shown, the voltage output from *T*11 will have the phase relationship shown by the solid line in figure 9-15 (D). When this voltage is applied to the leveling torque motor, it will cause the gyro's axis to precess back to the horizontal position, and thus reduce the level pickoff voltage to zero.

Had the gyro's axis been displaced in the opposite direction, the input signal to *V*16 and output from *T*11 would be as represented by the dashed lines in figure 9-15 (B) and (D). The leveling motor would then have caused the gyro to precess in the opposite direction.

OPERATION SUMMARY

The manner in which the various elements of the system function is described in the following paragraphs.

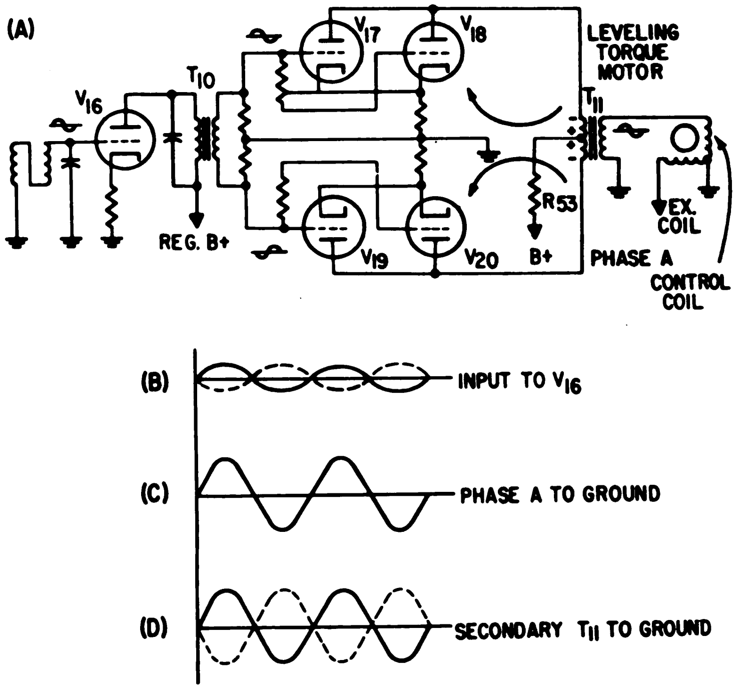


Figure 9-15.—Leveling amplifier circuit.

During this description you should refer to figure 9-10 which is an overall schematic of the system.

Compass Controlled Operation

The electrical output of the synchro transmitter *S*5 in the gyro unit corresponds to the position of the gyro spin axis. This output is fed to a synchro differential *S*4 in the controller. The electrical output of the synchro differential corresponds to the angular position of the gyro spin axis plus the angular mechanical position of the synchro differential rotor. The output of the differential is fed to a synchro control transformer *S*1 which is coupled electrically to a servo shaft in the amplifier. The synchro control transformer rotor produces a signal that corresponds to the difference between the angular position of the servo shaft. This signal is amplified by the servo amplifier and applied to the control phase of the

servomotor #1. The servomotor rotates the control transformer rotor (servo shaft) to null the output of the control transformer. The direction of the electrical field in the control transformer *S*1 is determined by the mechanical position of the synchro differential rotor plus the electrical signal from the synchro transmitter *S*5. When the rotor of the synchro control transformer *S*1 is alined with the electrical field across the stator of *S*1, no signal will be transmitted to *V*5 in the servo amplifier. The rotor of the synchro control transformer *S*1 will follow any movement in the rotor of *S*4 or the electrical field of *S*5.

The compass detector synchro *S*2, which is mechanically coupled to the servo shaft, produces a signal that is a function of the difference between the magnetic compass heading and the angular position of the servo shaft. This signal is amplified in the compass amplifier and converted to a direct current that flows through the synchronization indicator to the slaving torque motor of the gyro and causes the gyro to precess slowly. Precession of the gyro causes the servo shaft to rotate in the direction that brings the output of the compass detector synchro *S*2 to a minimum. Since the gyro precesses slowly, only the average compass heading is obtained.

When the system is initially energized, there may be a large discrepancy between the compass heading and the angular position of the servo shaft. Due to the slow precession rate of the gyro, a long period of time would be required for the gyro position and magnetic heading to become synchronized. However, by rotating the shaft of the synchro differential *S*4 and observing the indications on the synchronization indicator, the servo shaft is quickly alined with the compass heading by manual means.

Free Gyro Operation

During free gyro operation, a latitude compensation voltage, which varies in magnitude with latitude, is applied to the gyro's slaving torque motor coils. The rate of precession at a given latitude is such that it exactly opposes the apparent precession of the gyro caused by the earth's rotation.

Before takeoff, the aircraft's heading is set on the output synchro (compass indicator) by rotating the synchro

differential in the controller unit to the proper position. During the flight the gyro will then hold the rotor of the compass indicator in the same position in space. Therefore, assuming that grid navigational charts are used, the compass indicator will always indicate the aircraft's heading.

System Operational Checks

An operational check of the compass system should be included in the preflight check of the aircraft. This assures that the compass system is operating properly and is ready for the flight. When troubleshooting the system, an operational check of the compass system will be necessary before it can be determined which component or part of the system is at fault.

The *Handbook of Maintenance Instructions* for the aircraft or the *Handbook of Service Instructions* for the compass system will give the step-by-step procedure for this check.

The values of the input voltages to the compass system are of prime importance. The required a-c voltage is 200-volt, three-phase, 400-cycle, with a grounded neutral and a phase rotation of ABC. The compass system also requires a 27.7 d-c voltage supply.

Troubleshooting

Many times a complete component of a system has been unnecessarily replaced, when, if the troubleshooter had investigated further, he would often have found that only a new fuse or tube would have corrected the fault. Changing a complete component to correct a fault is very costly and time consuming. However, it is true that in some cases a new component will have to be installed.

A troubleshooting chart is very useful and can save hours of work if it is well planned. Such a chart should contain a listing of the major components of the system, the major parts of each component, and a brief description of how the system acts when a particular part fails. The leading petty officer of the electric and instrument shop is responsible for the development and use of such a troubleshooting chart for the particular MA-1 compass system being used in his squadron.

QUIZ

1. The purpose of the antispin motor in the GE MA-1 compass gyro control is to
   a. prevent gimbal lock
   b. eliminate nutation of the gyro
   c. lock the gimbals
   d. hold the MDI compass card stationary

2. The transmitter used with the GE MA-1 compass is
   a. not gyro stabilized directionally
   b. held parallel to the aircraft's lateral axis
   c. slaved to magnetic null by synchronization
   d. not directly used during synchronization

3. The latitude compensator in the GE MA-1 compass system is basically a/an
   a. RC network
   b. voltage divider
   c. phase discriminator
   d. all of the above

4. When the MA-1 compass is in free operation, a small latitude compensation voltage is fed to
   a. the left torque motor coil
   b. the right torque motor coil
   c. either torque motor coil
   d. both torque coils to hold the gyro erect

5. Leveling torque of a directional gyro is applied to the
   a. inner gimbal
   b. outer gimbal
   c. gyro horizontal axis
   d. gyro vertical axis

6. Slaving torque of all directional gyros
   a. depends on the time-phase relationship of the a. c. on the torque coils
   b. is proportional to the amount of misalinement between gyro and transmitter
   c. is applied to the inner gimbal
   d. is applied to the outer gimbal

7. A long period of time is required for the gyro and the magnetic heading to reach a null, due to slow precession rate. This is overcome (fig. 9-7) by
   a. caging the gyro normally
   b. rotating synchro differential (S4)
   c. rotating earth magnetic field in transmitter
   d. rotating gyro synchro (S5)

8. During free gyro operation, the maximum drift per hour specified for a MA-1 type compass is
   a. 2 degrees
   b. 4 degrees
   c. 6 degrees
   d. 8 degrees
9. The fluxvalve detector is kept horizontal by a
   a. vertical gyro
   b. pendulous mounting
   c. directional gyro unit
   d. pivot and float assembly
10. The freedoms of movement of the directional gyro are
    a. spin, tilt, tilt
    b. spin, tilt, turn
    c. spin, turn, turn
    d. spin, tilt
11. Synchronization of the GE MA-1 compass system is accomplished by
    a. caging the gyro
    b. rotating the fluxvalve field
    c. rotating the gyro element
    d. rotating the magnetic null position of the gyro
12. The fluxvalve transmitter compensating screws compensate for
    a. soft iron error
    b. variation
    c. deviation
    d. single cycle error
13. In the MA-1 directional-gyro rotor, the purpose of the two stators is to
    a. compensate for turn error
    b. maintain a constant moment of inertia
    c. provide for maximum angular velocity in the rotor
    d. reduce weight
14. The rotor of the directional gyro is free to turn about its
    a. lateral axis
    b. horizontal axis
    c. normal axis
    d. vertical axis
15. A gyroscope at the equator with its spinning axis horizontal and pointing N-S, will
    a. apparently drift about its horizontal axis only
    b. apparently turn about its vertical axis only
    c. exhibit no apparent change
    d. have apparent tilt about both axes

16. Bias for the frequency doubler in the GE MA-1 compass amplifier is obtained from
    a. the B-plus supply
    b. aircraft's a-c supply
    c. aircraft's battery (d-c) supply
    d. transformer action

CHAPTER 10

AUTOMATIC FLIGHT CONTROL AND STABILIZATION SYSTEMS

The first electronic automatic flight control and stabilization (AFCS) system to be installed in naval aircraft was the Eclipse-Pioneer P-1 automatic pilot. The P-1 is a closely integrated system which was ideally suited to the requirements of the then current propeller driven, piston engine aircraft. It served a dual purpose of providing direction and attitude indications to the pilot as well as stabilization signals for autopilot control.

While highly satisfactory operation had been obtained in the earlier aircraft, test indicated that the system did not provide adequate control, nor did it provide all of the features desired in later aircraft. Hence, development of the Eclipse-Pioneer P-3, the General Electric G-3, and the Sperry S-5 was undertaken.

The theory and operation of the P-1 automatic pilot is discussed in the Navy Training Course, *AE 3 & 2*, NavPers 10348. The operation of this autopilot is entirely electrical. It provides magnetic heading control, automatic synchronization, and maneuvering control. To these features the P-3, G-3, and S-5 autopilots added barometric altitude control, increased the maneuvering limits, and included three axes rate damping. They also provided improved servo response and increased vertical gyro accuracy.

During the period of transition from the P-1 autopilot to the P-3, G-3, and S-5, considerable changes developed in naval aircraft. The jet engine produced a greater speed

range and higher control forces, which required the installation of boost or full power surface control systems. During the development of an aircraft, numerous aerodynamic and control system changes are made to obtain the specified performance characteristics. In many cases these changes necessitate corresponding changes in automatic flight control systems. Therefore, it has been determined that the best coördination of the overall airframe automatic stabilization system development can be obtained by placing the responsibility for furnishing satisfactory equipments in the hands of the airframe manufacturer; and that all automatic flight control systems would be contractor furnished.

This policy introduces new problems in the maintenance, training, and publication areas. Special handbooks, field test sets, personnel training, and spare parts must be provided to support each aircraft type system installation.

It would be beyond the scope of this training course to discuss each and every type of automatic flight control and stabilization system. However, with knowledge of the basic functions of the autopilot and some of the newer developments, this chapter will familiarize you with the operation and function of the newer type automatic flight control and stabilization system that you must maintain.

A discussion of the various units that constitute these new type automatic flight control and stabilization systems will follow. Discussion will be given to altitude control, and yaw and pitch stabilization. Also, a present-day automatic flight control and stabilization system that is installed in a late model aircraft will be discussed.

It is suggested that you become familiar with the information contained in chapter 15 of *AE 3 & 2,* NavPers 10348, before continuing with your study of this chapter.

ALTITUDE CONTROL

In order to maintain the aircraft at a fixed altitude, some autopilots include an altitude control feature. The altitude controller consists of an aneroid, a mechanism for transmitting and magnifying the motion of the aneroid, a solenoid operated clutch, a synchro, and a centering device for returning the synchro rotor to the null or no-signal position.

The aneroid consists of two diaphragms which are sealed internally at standard (sea level) barometric pressure. The two diaphragms are connected in tandem on a single pushrod and mounted in an airtight case. The case is connected by a tube to a source of static air pressure. The diaphragm pushrod is mechanically connected to one of the clutch plates through a linkage consisting of a lever, a pivoted shaft to which is attached a gear sector, and a pinion gear.

Any departure of the aircraft from the barometric pressure altitude at which the altitude control switch is set, produces movement of the aneroid diaphragms. This motion is transmitted through the linkage to displace the rotor of the synchro, resulting in the generation of a signal in the synchro stator. This signal is applied to the elevator channel to produce elevator control for returning the aircraft to the pressure altitude indicated by the aneroid. When the aircraft reaches the correct altitude, the synchro signal becomes zero and elevator control is maintained through normal autopilot channel operation.

When the altitude control switch is turned off, the clutch and the centering device actuating coil are deenergized. This opens the clutch to disengage the synchro rotor from the aneroid mechanism and, at the same time, the centering yoke, by spring action, closes on the synchro rotor shaft lever to return the rotor to the null or no-signal position.

In this way, the synchro rotor is always held at the no-signal position whenever the altitude control is off, and since the clutch is disengaged, the aneroid is free to move. Therefore, the altitude control may be engaged at any time. Regardless of the position of the aneroid, the altitude that it senses will be the one used as the reference for maintenance of constant altitude when the altitude control is turned on. It is not necessary to wait for synchronization or alinement.

Figure 10-1 (A) shows a three-quarter view of a barometric altitude control. The outside appearance of various controls of this type will vary depending upon the manufacturer; however, the working parts will be similar. Figure 10-1 (B) shows the internal parts of a barometric altitude control, while figure 10-1 (C) shows the simplified schematic of the altitude control.

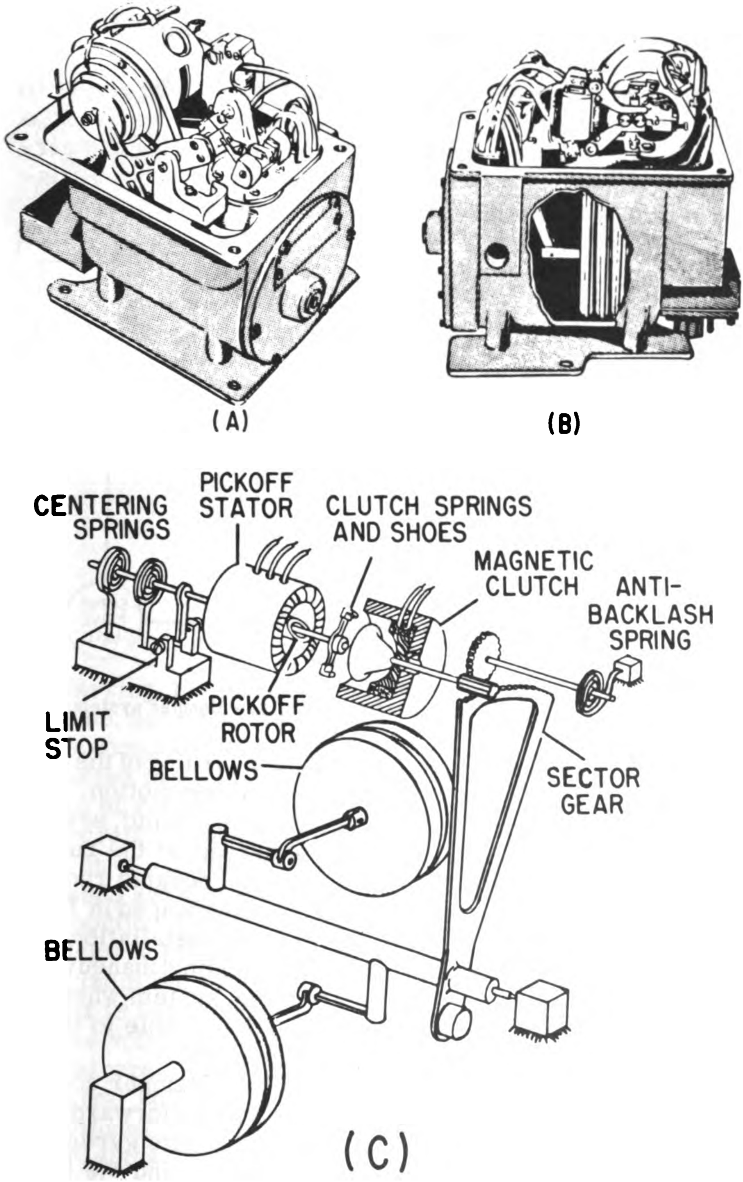


Figure 10-1.—(A) Barometric altitude control; (B) internal parts; (C) simplified schematic.

YAW STABILIZATION SYSTEM

Many high-speed fighter aircraft have tendencies to oscillate about their vertical (yaw) axis. The use of a yaw damper system aids the pilot in stabilizing the aircraft against oscillation about its yaw axis. A block diagram of a typical installation is shown in figure 10-2.

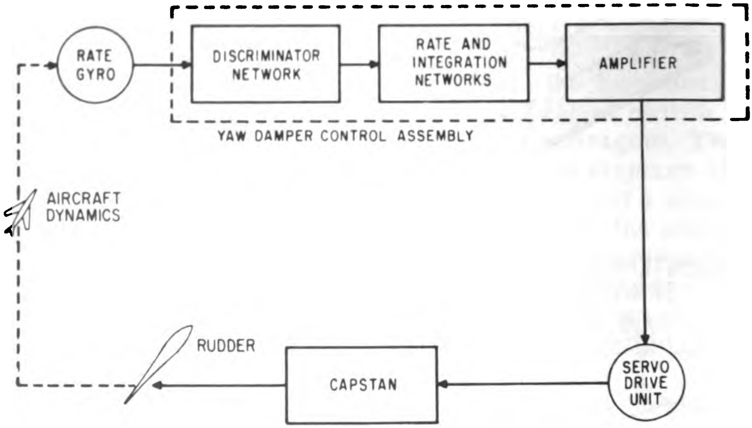


Figure 10-2.—Block diagram of a typical yaw damper system.

The yaw damper detects any sudden turning of the aircraft and deflects the rudder to oppose the motion. The movement of the rudder may be relatively rapid, several cycles per second, and may be observed at the rudder pedals of any aircraft not using a power operated rudder. The yaw damper may be engaged and disengaged in flight at the discretion of the pilot. In most installations, in order to free the rudder for takeoff or landing maneuvers, a switch automatically disengages the system when the wheels are down. In any case, the pilot is able to overpower the unit should it become necessary.

The basic unit of the system is the yaw damper control assembly (fig. 10-3), which is located in the forward part of the aircraft. This unit contains the rate gyroscope which senses changes in aircraft heading, and the electronic circuits necessary to transform the information from the rate gyro into signals that can be used to control the rudder servo.

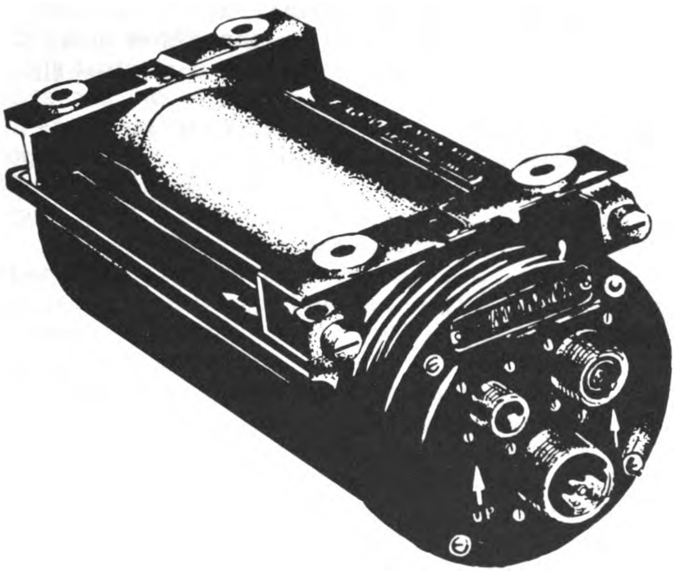


Figure 10-3.—Yaw damper control assembly.

Referring to the block diagram shown in figure 10-2, it can be seen that the yaw damper system is relatively simple compared to a complete autopilot. The rate gyro is mounted in gimbals and is restrained by springs so that its axis of rotation is normally parallel to the roll axis of the aircraft. When the aircraft turns about its yaw axis, either in a coordinated turn or ordinary yaw, the gyro precesses against the springs. The degree of precession is proportional to the rate at which the aircraft is turning. An inductive pickup mounted near the rotor furnishes the signal from the gyro for the rest of the system. When the aircraft is not turning and the gyro is in its neutral position, the voltage induced in the pickup by the gyro is zero. If the aircraft yaws or turns, the gyro is displaced from its neutral position by precessional torques, and a voltage proportional to the rate of turn is induced in the pickup.

The signal will be either in phase or 180 degrees out of phase with the current in that leg of the three-phase incoming a-c power that is used in the yaw damper control assembly as a reference. Whether the signal is in phase or out of phase depends on the direction in which

the aircraft is turning or yawing. The signal from the pickup is compared with the reference phase in the discriminator network, which produces a d-c output signal. This signal's voltage is proportional to the a-c signal voltage and its polarity is determined by the phase difference. Note that this phase difference is NOT proportional to the rate of turn. It is either zero degree or 180 degrees, depending only on the direction of turn. Signal amplitude is proportional to the rate of turn.

The yaw signal, now in the form of a d-c voltage varying as the aircraft turns, is next passed through rate and integration networks. The purpose of the rate network is to "quicken" the system; that is, to provide a phase lead in the slowly varying d-c signal that is applied to the servo amplifiers. This lead will compensate for the phase lag introduced by the servodrive and rudder. At the same time, the integration network shapes the frequency response curve of the system to keep the range of operation within the stable portion of the aircraft's control characteristics. The last section of the yaw damper control assembly consists of a two-stage amplifier. The first stage amplifies the signal from the rate network an amount required to give efficient yaw damping and at the same time stable operation. The second stage furnishes the power required to actuate one of the two magnetic power clutches in the servodrive unit located in the vertical stabilizer. The polarity of the control signal from the control assembly determines which clutch is engaged.

The servodrive unit positions the rudder, in response to the control signals from the control assembly, through a clutch and drum assembly. The clutch is an adjustable-mechanical type and is incroporated in the drum unit to permit manual override of the system in case of emergency. It also limits the torque applied to the control surface to the value at which the clutch has been adjusted to slip.

It should be pointed out that the rate network will not respond to steady signals from the rate gyro such as would be produced if the aircraft were turning at a constant rate for a period of time. The damper is designed in this manner so that the pilot does not have to overpower the servo to turn the aircraft. While the rate network does remove the steady state component of the signal from the

rate gyro, it still passes transients due to yaw, and the yaw damper system is still operative in the turn.

PITCH AND YAW STABILIZATION SYSTEM

It has been found necessary to stabilize some aircraft in the pitch axis as well as the yaw axis in order to prevent oscillations of the aircraft. This type of stabilization system is similar to the yaw damper system just discussed, in that it uses gyroscopes to create signals indicative of the movement of the aircraft in yaw and also in pitch.

Two signals are required in this system. One indicates the rate of movement in yaw (angular velocity about vertical axis), and the other indicates the rate of movement in pitch (angular velocity about the lateral axis).

In this stabilization system two rate gyro units are used. One with the sensitive axis parallel to the yaw axis of the aircraft and the other with the sensitive axis parallel to the pitch axis of the aircraft.

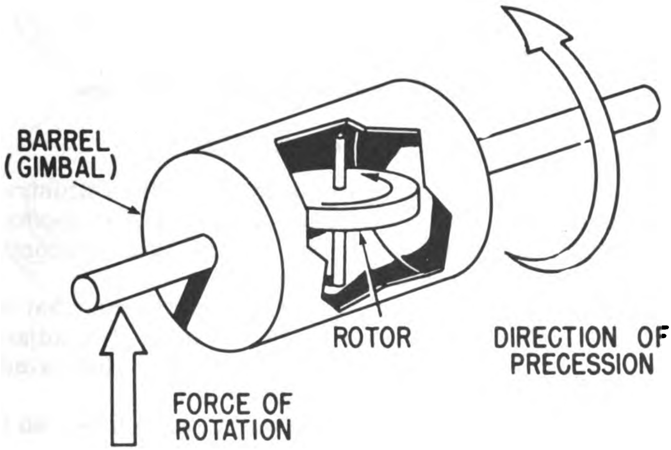


Figure 10-4.—Single sensitive axis gyro mounted in a barrel assembly.

The gyro rotor is mounted in a barrel assembly (fig. 10-4) which in effect takes the place of the gimbal. Shafts extend from the ends of the barrel along the free axis of the device so that the barrel rotates on these shafts when

the gyro precesses. A signal generating device is mounted on the end of the shaft. This device gives indications of the amount and direction of rotation of the barrel. The entire assembly, with restraining springs, is mounted as indicated in figure 10-5.

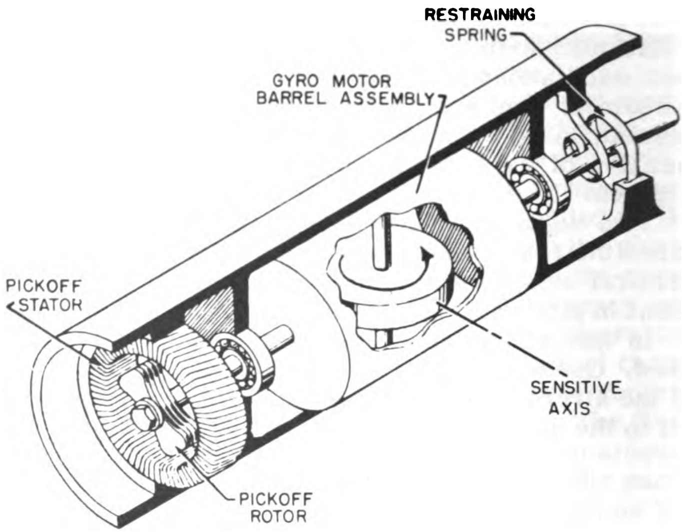


Figure 10-5.—Mechanical schematic of rate gyro.

Signal Generator Pickoff

The principle of operation of the pickoff is illustrated by figure 10-6. The stator is made up of ring-shaped laminations and has four poles. A primary and secondary coil is wound on each of these poles.

The primaries are connected to each other so that with 115 volts, 400 cycles applied to the input, two adjacent poles have the same polarity at any instant. (Indicated by N-N and S-S for the instant illustrated.)

The secondaries are connected to each other so that the voltages induced into them by the primaries are opposite in polarity for adjacent poles (indicated by the voltage curves inside the rings) but of the same polarity for opposite poles. A rotor, made up of laminations and mounted on a shaft within the poles, is used to vary the output voltages of the pickoff to indicate the direction and amount of rotation of the shaft.

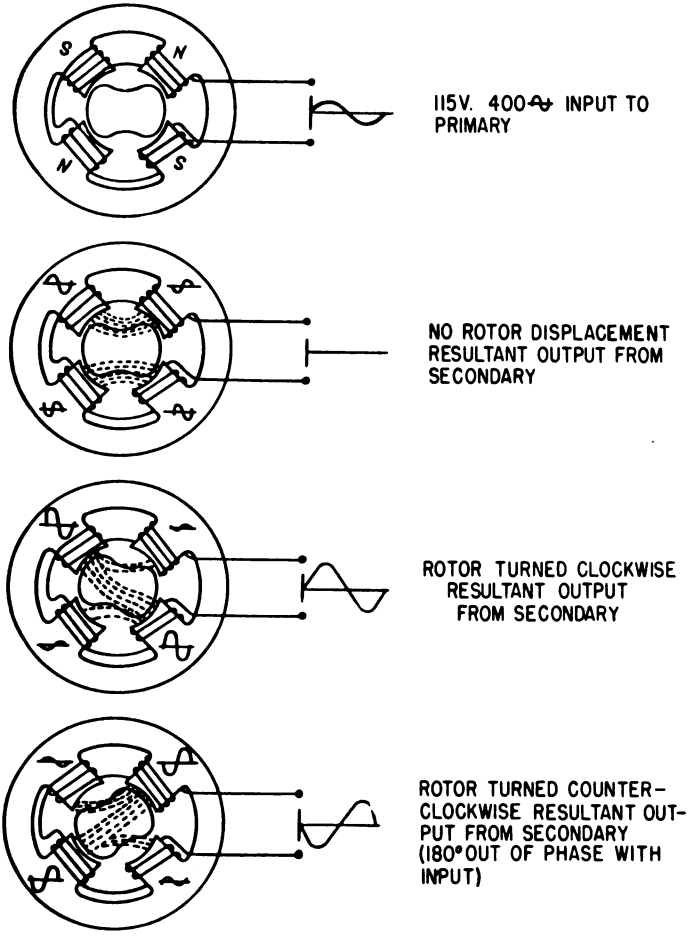


Figure 10-6.—Rate gyro pickoff operation.

Control Surface Effectiveness

At different altitudes the atmospheric pressure varies so that the effect of the control surfaces in maneuvering the aircraft changes with altitude. For a given speed, at the rarefied atmosphere of high altitudes it takes a greater displacement of the control surfaces to obtain the same effect as at a lower altitude.

Changes in speed of the aircraft also vary the effectiveness of the control surfaces. At a given altitude, slow speeds require more control surface movement than high speeds if the same amount of maneuvering is to be accomplished.

Since the gyro signal outputs are dependent only on the rate of change in altitude, for any given rate of change the signal will be of the same magnitude regardless of the speed or altitude at which the aircraft is flying.

Gain Control Unit

To compensate for changes in altitude and airspeed, the signals are modified by a gain control unit. This unit makes use of the difference between the pressure created by the flight of the aircraft (ram pressure) at different speeds and altitudes, and the pressure inside the aircraft at different altitudes caused by barometric pressure alone (static pressure). Figure 10-7 shows a mechanical schematic of the gain control unit. It can be seen in the schematic that as the dynamic air pressure increases, the bellows will cause the spring to become more compressed. This allows the armature to move each potentiometer's sliding arm to select the adequate portion of the rate gyro signals in accordance with the altitude and airspeed of the aircraft.

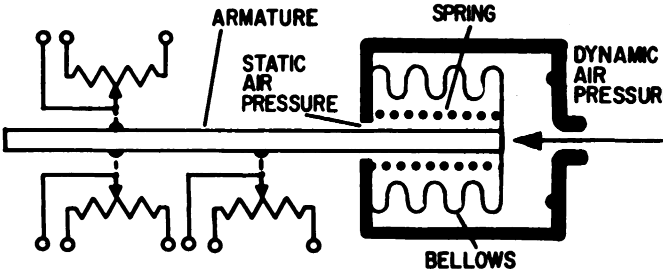


Figure 10-7.—Mechanical schematic of gain control unit.

As the airspeed decreases or when the aircraft's altitude decreases, the armature will move to the right, selecting a different portion of the rate gyro's signals.

Airstream Direction Detector

At the considerably slower speeds of landing and takeoff, additional corrective control surface movement is required to provide increased stability in yaw. The signal gradient of the gyroscope is not sufficient to provide this stability.

An airstream direction detector measures the amount the nose of the aircraft points out of the airstream and generates signals to cause corrective rudder movements. This device will correct not only for yaw but for skids and slips. The unit will detect deviations of the airstream within one-tenth of a degree.

Figure 10-8 shows the mechanical schematic of a typical airstream direction detector.

The airstream direction detector is mounted inside the aircraft. Its probe is thrust through the skin and extends down into the airstream. Two slots on the probe admit pressure. This pressure, which is caused by the airstream, acts on a vane (paddle) inside the paddle-chamber. Each slot is connected through an orifice to a different side of the paddle-chamber. When the airstream strikes one slot more directly than the other, the pressure on that side of the paddle-chamber becomes greater than on the other side, causing the paddle to move. The paddle is connected by linkage to the probe and the moving arm of the potentiometer. When the paddle moves it turns the probe so that the two slots again face evenly to the airstream. Also when the paddle moves the potentiometer arm is moved and creates an unbalance in the yaw channel circuit.

Since this increased stability in yaw is needed only during landing and takeoff, the unit is connected into the system only when the wing flaps are extended. When the wing flaps are extended, a switch is allowed to close. When the switch closes, it operates a relay which connects the airstream direction detector into the yaw channel.

System Operation

The signals from the rate gyros, generated by the gyro pickoffs when the gyros precess, go to the gain control

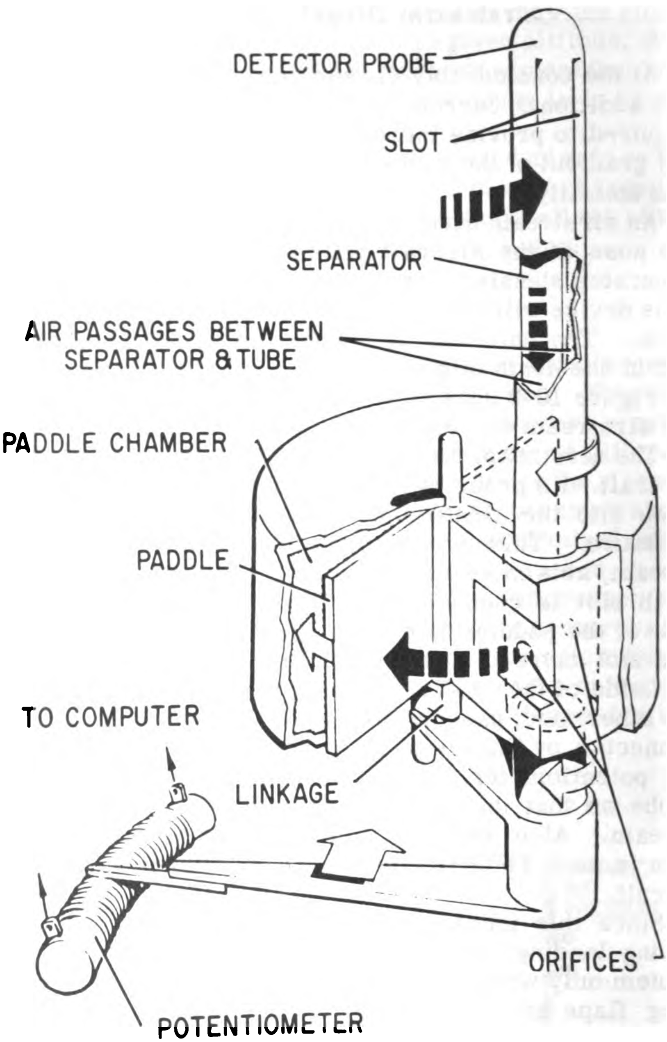


Figure 10-8.—Mechanical schematic of airstream direction detector.

unit where they are modified. The signal in the pitch channel then goes to transformer *T*301 where it is coupled to the pitch channel servo loops. Figure 10-9 shows a diagram which illustrates this operation.

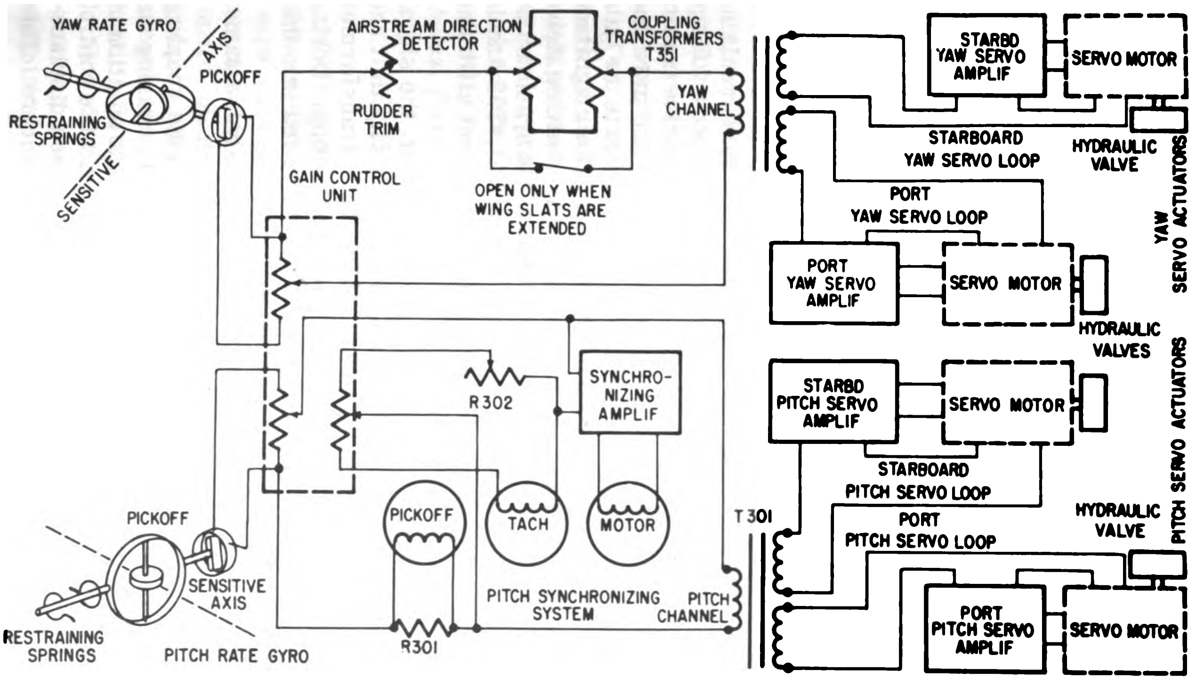


Figure 10-9.—Simplified schematic of stabilization system.

This channel also contains a synchronizing system which consists of a synchronizing drive unit and a synchronizing drive amplifier. The system is useful during maneuvering, when the pilot is moving the aircraft in pitch. When the aircraft moves in pitch, the pitch gyro creates a signal that goes to the servo loop to oppose the movement of the aircraft. The synchronizing system provides a signal that cancels the gyro signal. This causes the servo loop to sense a zero signal, as if there had been no movement of the pitch rate synchro, and the servo actuator will return to the zero position. The circuit and the mechanical drive are designed so that they will not prevent damping of oscillation or oppose the pilot's control of the aircraft.

The opposing signal, produced by the synchronizing system, appears across resistor *R*301. The synchronizing system tachometer is a generator that produces a voltage proportional to the speed of the synchronizing drive motor. This voltage opposes the signal created by the gyro and appears across resistor *R*302 and the resistor in the gain control unit which is in series with *R*302. The magnitude of the signal controls the speed of the synchronizing drive motor and thus determines the response of the synchronizing system. The signal may be adjusted at *R*302 and is also adjusted by the gain control unit for different altitudes and airspeeds.

After passing through the gain control unit, the signal in the yaw channel goes through the rudder trim unit and then to coupling transformer *T*351. This transformer couples the signals to the yaw channel servo loop. During takeoffs and landings an additional signal is fed into this channel by the airstream direction detector.

The servo loop in each channel is essentially the same; therefore, an explanation of only one is given.

When a signal appears across the input of the coupling transformer it is fed to the servo amplifier, causing the servomotor to operate a hydraulic valve. The position of the valve determines the position of the aircraft's control surface. As the motor rotates, it also causes displacement of the rotor of the servo followup synchro. This action generates a signal that opposes the output signal of the coupling transformer. When this opposing signal attains a certain magnitude the servomotor stops. If the

signal input to the coupling transformer is changed the servomotor will rotate to match this change.

If the signal input to the coupling transformer gives a zero output from the transformer, the servomotor will bring the control surfaces back to the zero position. In a maneuver, when the pilot is causing the aircraft to change pitch at a relatively steady rate, the servo actuator will turn to its zero position. This occurs because the synchronizing or pitch canceler system will have created a signal in opposition to the gyro signal. There would then be no output signal from the coupling transformer and the servo pickoff would match a zero signal.

The tachometer in the servo loop has a damping effect on the servodrive motor. As the control surfaces approach the desired position, the tachometer output signal will oppose the tendency of the servodrive to overshoot.

It would be possible to stabilize the roll axis of an aircraft by the use of a third rate gyro. When an oscillation occurred about the longitudinal axis of the aircraft a signal would be created to correct for the oscillation.

The stabilization system just discussed should give a working understanding of any stabilization system you are required to maintain. For complete operating details and servicing instructions, refer to the *Handbook of Operation and Service Instructions* on the system. Handbooks of this nature are listed in the *Naval Aeronautic Publications Index,* Part I, Instruments Section, 05 series.

PENDULUM ERECTING VERTICAL GYRO

In the days when automatic pilots were controlling slow-speed aircraft, the gyros used for flight references were erected manually. An example of this is the ball erection system used in the vertical gyro of the P-1 automatic pilot. Today, with aircraft traveling at a much greater rate of speed, it is necessary to have an improved means of erecting the flight reference gyros used in automatic pilots and stabilization systems.

One of the most common of these newer methods of erecting gyros is by the use of a pendulum device. By definition, a pendulum is "a body so suspended from a fixed point as to swing freely to and fro under the combined action of gravity and momentum."

The pendulum device is used as a vertical reference point for the vertical-seeking gyro. Under static conditions the mass of the pendulum will always seek the earth's vertical axis. If any differences arise between the pendulum axis and the gyro axis a corrective action of the vertical gyro will take place.

Figure 10-10 (A) is a mechanical schematic of a vertical gyro which shows its three axes of movement. These movements may be about the vertical axis, lateral axis, and longitudinal axis.

In order to keep a vertical gyro erect, the gyro's spin axis must be perpendicular to the earth. If a pendulum is mounted to the frame of the gyro so that its pivot axis is the same as the pivot axis of the outer gimbal, the pendulum will detect an error any time the gyro axis (frame) is not perpendicular to the earth in pitch attitude. Likewise, if a pendulum is mounted so that its mass is pivoted parallel to the longitudinal axis a comparison of the pendulum and the gyro's vertical axis in roll attitude can be made.

Vertical gyro units, as used in automatic flight control systems, detect roll about the longitudinal axis of the aircraft (bank), and pitch about the lateral axis of the aircraft (dive or climb). Detection is achieved by picking off signals from the pitch synchro and the roll synchro. The pickoff signals measure the deviations in roll and pitch. The magnitude and phase relationship of the generated electrical signals are proportional to the difference between gyro attitude and airframe attitude. The pickoffs (synchros) consist of two major parts, a rotor and a stator. The pitch pickoff rotor is attached to the inner gimbal, at the pivot point, and its stator is attached to the outer gimbal. The roll pickoff rotor is attached to the outer gimbal pivot pin, and its stator is attached to the gyro frame.

The gyro erection pendulums (pitch and roll) consist of a synchro pickoff and a weighted arm. The weighted arm is rigidly attached to one end of a shaft which is free to turn in ball bearings. The pickoff rotor is attached to the other end of this shaft. The synchro pickoff stator is attached to the pendulum's housing and then to the gyro frame.

The gyro-erecting system utilizes two torque motors. These are two-phase induction motors and each contains a rotor and a stator. The roll-axis torque motor is mounted with its torque axis parallel to the longitudinal

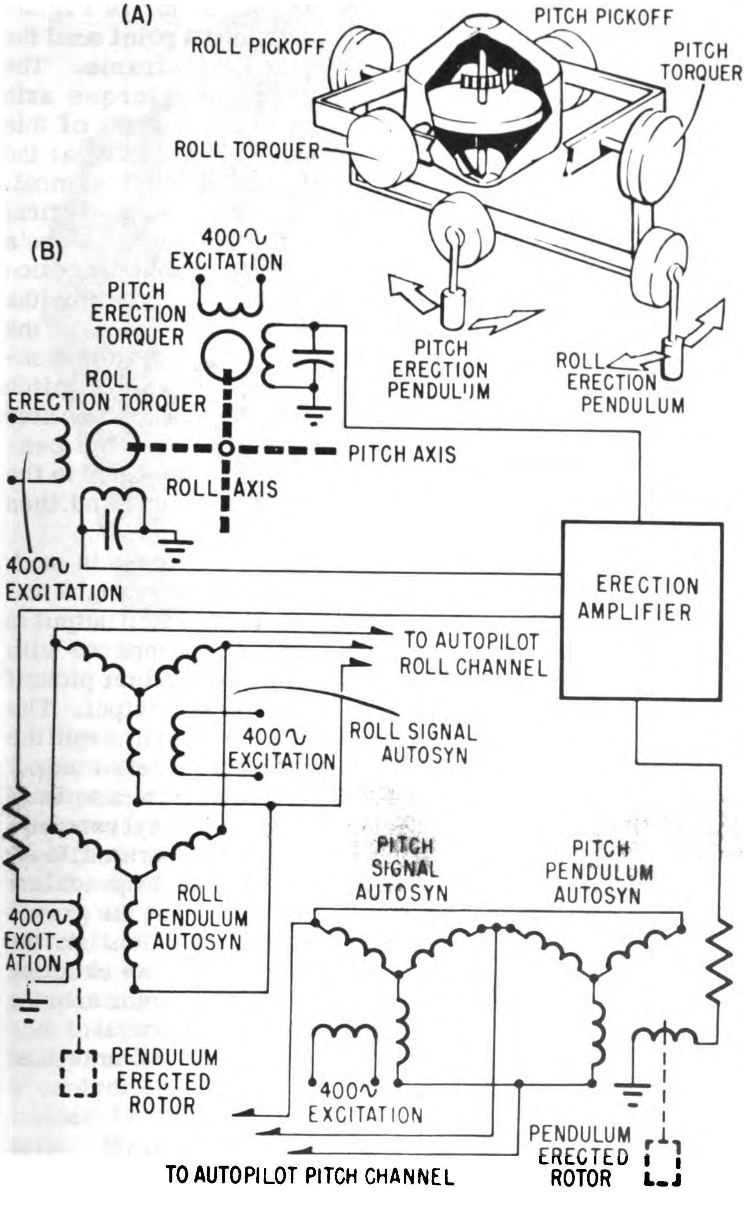


Figure 10-10.—(A) Mechanical schematic of a vertical gyro; (B) simplified electrical diagram of vertical gyro.

axis of the aircraft. The rotor of this motor is rigidly attached to the outer gimbal ring at its pivot point and the stator is attached to the outside of the gyro frame. The pitch-axis torque motor is mounted with its torque axis parallel to the lateral axis of the aircraft. The rotor of this motor is rigidly attached to the inner gimbal ring at the gimbal pivot and the stator is attached to the outer gimbal.

The vertical gyro spin axis may not be in a vertical position when the gyro is started. Because of the gyro's tendency to maintain its spin axis in one space direction regardless of its position with respect to the earth, the gyro erection system acts to position and to maintain the gyro spin axis in a vertical position. This system consists essentially of the pitch and roll gyro pickoffs, pitch and roll pendulum pickoffs, and two torque motors mounted on the two horizontal axes (pitch and roll axes). The pendulum synchro pickoffs have their rotors connected to the bob (mass), and their stator to the pendulum case and then to the gyro frame.

Each pendulum case is mounted on the gyro case in such a manner that when the aircraft is in normal (straight and level) unaccelerated flight, the pendulum pickoff output is zero. The roll pendulum pickoff output is compared with the gyro roll pickoff output and the pitch pendulum pickoff output is compared with the gyro pitch pickoff output. The gyro pickoffs have signal gradients identical to those of the corresponding pendulum pickoffs, and have zero output only when the gyro axis is vertical and the gyro case is in the position it would have during straight and level unaccelerated flight. Therefore, in normal, unaccelerated, level flight, any inequality between the outputs of the pendulum and gyro pickoffs on either axis indicates that the gyro's spin axis is off vertical by an amount proportional to the error signal. These error signals are fed to an erection amplifier which energizes the proper torque motor to bring the gyro spin axis into alinement with the vertical.

Figure 10-11 shows a vertical gyro control unit used in fighter type aircraft.

Pendulum Control Unit

The function of the pendulum control unit is to control the aircraft's rudder, causing the aircraft to make coordinated maneuvers at all speeds.

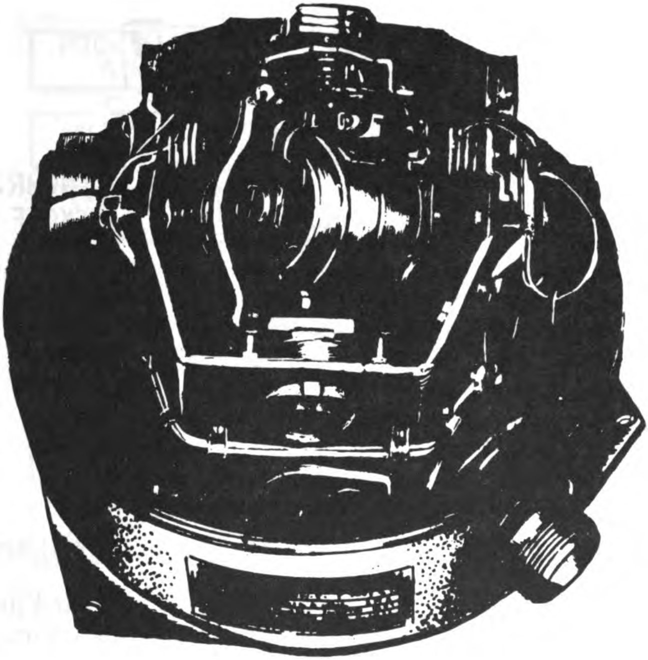


Figure 10-11.—Vertical gyro control unit.

Figure 10-12 shows a rate and pendulum control unit. It consists essentially of a pendulum, a pendulum damper (dashpot), a synchro pickoff, and three rate gyros with synchro pickoffs for each. In a turn the aircraft and the pendulum are subjected to two forces—centrifugal force and the force of gravity. When the resultant of these two forces is perpendicular to the deck of the aircraft, the aircraft is in a coordinated turn. If the turn is not coordinated, the pendulum is displaced from its minimum output position (position perpendicular to deck of aircraft), and the pendulum pickoff produces a signal proportional to the pendulum displacement. This signal is fed through a control amplifier of the rudder servo which drives the rudder in the proper direction to obtain a coordinated turn. When the turn becomes coordinated the pendulum returns to its minimum pickoff output position.

Pendulums that are used in automatic pilot installations vary depending upon the particular system. However, the

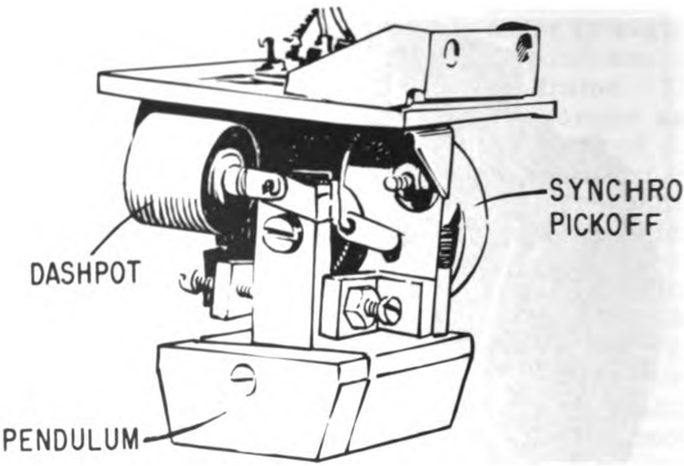


Figure 10-12.—Rate and pendulum control unit.

operating principles that have been discussed will apply to all systems.

The three rate gyros (yaw rate, roll rate, and pitch rate) supply attitude stabilization for all three automatic pilot channels, while in full automatic pilot mode.

AUTOMATIC FLIGHT CONTROL SYSTEM

An automatic flight control system provides the pilot relief from routine flight duties, improves the utility of the aircraft, and augments the aircraft's flying qualities so that difficult operational tasks may be conducted more readily. These tasks include instrument flying, bombing and mine laying, night fighting and interception, and field and carrier landings. In general, the objective is to provide a better link between the pilot and the airframe than the conventional stick and pedals provide.

Figure 10-13 shows a block diagram of a typical autopilot system used in a late model naval aircraft.

The automatic pilot system consists of three separate channels—pitch, roll, and yaw. Each individual channel receives its own source of intelligence from synchros located in different attitude sensors.

The PITCH CHANNEL has a source of four individual signals. These are the pitch rate gyro, the altitude controller, the vertical gyro, and the stick controller.

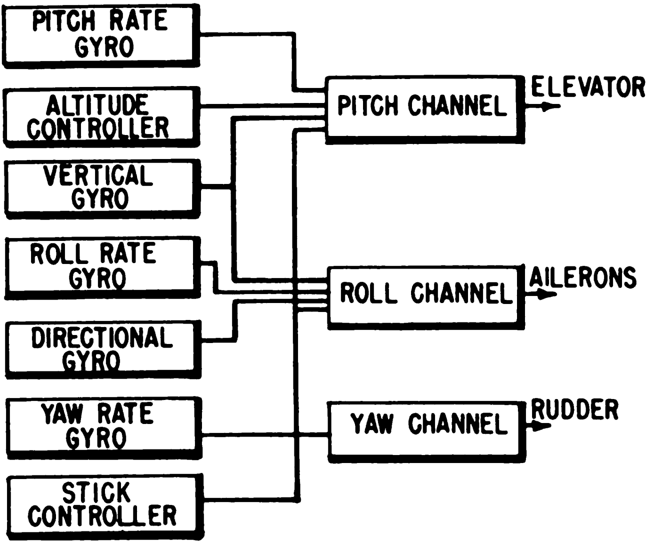


Figure 10-13.—Block diagram of a typical autopilot used in a late model naval aircraft.

The PITCH RATE GYRO, as explained earlier in this chapter, supplies an output signal. This signal is proportional to the rate of displacement of the aircraft about its lateral axis. This signal aids the autopilot system in holding the aircraft in a set altitude selected by the pilot; it also provides pitch stabilization separately.

The ALTITUDE CONTROLLER, as explained earlier, furnishes the pitch channel signals whenever the aircraft departs from a barometer altitude selected by the pilot. The pilot may engage or disengage the altitude controller any time he desires, by an altitude control switch.

The VERTICAL GYRO supplies two signals for the automatic pilot, one to the pitch channel and the other to the roll channel. The pitch signal is obtained from a pitch synchro which measures the amount of angular displacement of the aircraft about its lateral axis.

The STICK CONTROLLER contains various switches, potentiometers, pickoffs, and synchros through which the pilot can control the function of the autopilot. The principal elements of this unit are the pitch and roll maneuvering synchros and the pitch trim potentiometer.

Figure 10-14 (A) shows a typical stick type controller; figure 10-14 (B) is the mechanical schematic of the stick controller. As can be seen, if the stick of the controller is moved forward or aft by the pilot the pitch maneuvering synchro will be displaced from null. The strength of the signal from the pitch maneuvering synchro is proportional to the amount of displacement of the stick on the controller. The phase relationship of the pitch maneuvering signal depends on the direction of movement of the stick from its null position.

Basically, the pitch channel of the newer automatic pilots is the same as those in the earlier autopilots, as described in chapter 15 of *AE 3 & 2*, NavPers 10348. The signals transmitted to the pitch channel can be either a single source of intelligence or the sum of all synchro information of the pitch channel.

The roll channel operates quite similar to the pitch channel with the exception of the directional gyro signal. The directional gyro (compass system) signal in earlier autopilot systems controlled the rudder of the aircraft. This method caused the aircraft to skid and slip in a turn, and this became increasingly dangerous with high speed aircraft. By applying the directional signal to the roll channel, the aircraft's turn is achieved by the ailerons. The roll channel also receives a signal from the roll synchro, located in the vertical gyro. The roll synchro detects any displacement error about the aircraft's longitudinal axis, similar to the earlier autopilots. The third signal source of the roll channel is derived from the roll rate gyro. The roll rate gyro (synchro) signal is developed whenever the aircraft oscillates or yaws about its longitudinal axis. The signal output is proportional to the rate of oscillation about the longitudinal axis. The stick controller furnishes the command signal to the roll channel, just as it did for the pitch channel. By viewing figure 10-14 (B) it can be seen that if the control stick is moved from side to side, the roll maneuvering synchro will be rotated. The movement of the roll synchro rotor produces a roll command signal.

The pilot may simultaneously introduce signals into the roll and pitch channel by moving the control stick of the controller. This is done when the pilot wishes to make turns or maneuver the aircraft.

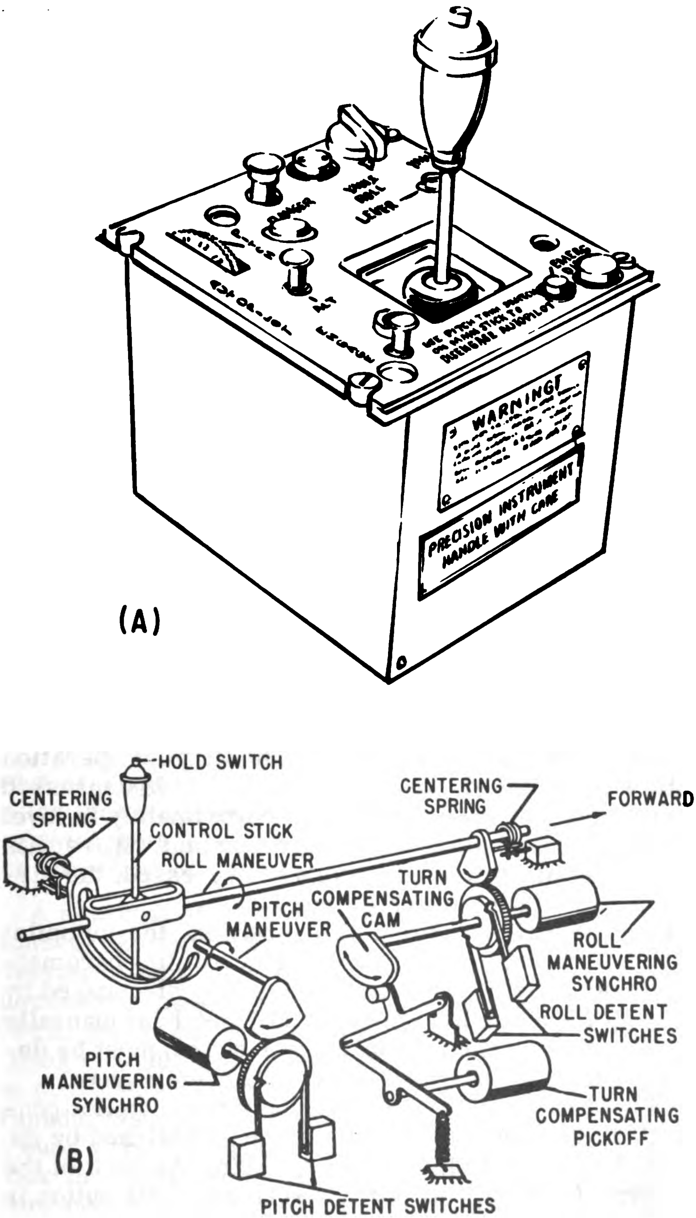


Figure 10-14.—(A) Stick controller; (B) schematic of stick controller.

The yaw channel is the simplest of the channels. It receives only one signal to cause the rudder to move. This signal is derived from the yaw rate gyro. The yaw rate gyro, which was explained earlier in this chapter, detects any oscillation or yawing of the aircraft about its vertical axis. The signal output of the rate gyro synchro is proportional to the rate of oscillation or yawing. The yaw channel that is shown in figure 10-13 is used only for stabilization.

The automatic pilot system that you maintain may utilize additional signals. These could appear in any of the three channels. Basically, every autopilot will be similar to the typical system shown in figure 10-13.

The stick-type controller, as mentioned before, contains various switches, potentiometers, pickoffs, and synchros through which the pilot can control the function of the autopilot (fig. 10-14 (A) and (B)). The controller contains the following switches—engage, damper, level, altitude, hold, damper selector, and emergency disconnect. All operating controls are accessible from the top of the case that encloses the unit.

The damper mode of autopilot operation can be engaged by pressing the damper button approximately twenty seconds after the engine has been started or after external power has been supplied. The damper button must be depressed before full automatic pilot operation can be accomplished. If the damper button is depressed during flight and the aircraft is approximately in level flight, the engage button can be depressed and will remain down. Once the engage button has been pressed, the aircraft operates at full autopilot control.

When the altitude button is depressed, the autopilot system will maintain the aircraft at the existing barometric altitude. The altitude button is easily disengaged by displacing the autopilot control stick in pitch, or manually pulling up the button. The engage button must be depressed before the altitude button will remain down.

The hold button, located on the top of the autopilot control stick, is used to hold an attitude established by the autopilot control stick, thereby relieving the pilot of the necessity of holding the stick displaced. This button is pressed down after a desired attitude has been obtained. The aircraft can be returned to level flight by pressing the

level button or by moving the autopilot control stick slightly and temporarily out of detent in pitch and roll. The level button returns the aircraft to level flight from any attitude while under autopilot control and with the autopilot control stick in detent.

The emergency disconnect button, when depressed, will disengage the damper system as well as autopilot control. Once the emergency disconnect button has been released, the entire autopilot engaging operation must again be performed in order to engage the autopilot.

The stick controller also houses a pitch trim wheel which enables the pilot to make minor adjustments in the aircraft's pitch attitude when under autopilot control. The amount of trim in any direction will vary with the initial trim setting, but a total of approximately 27-1/2 degrees is available. The aircraft should be trimmed manually prior to full autopilot engagement.

A roll trim potentiometer, located on the stick type controller, is used initially for roll trim adjustment. This can be used to correct for a slight bank that may exist at the time the autopilot is engaged.

These are some of the features that are incorporated in the later type automatic pilot systems. Becoming acquainted with the names and purposes of these controls will help you to better understand any autopilot that you may be required to maintain. For a detailed discussion of the theory of operation of these units and the sequence in which they operate, for a particular system, refer to the *Handbook of Operation and Service Instructions*.

A new type of AFCS is being introduced to fleet operations in the A4D-2N aircraft. It is called Control Stick Steering AFCS. Control Stick Steering means that the function of maneuvering the aircraft by means of the AFCS, which was formerly provided through the maneuvering controller (as depicted in fig. 10-14 (A)), will now be provided in the pilot's stick or control wheel. Force transducers have been built into the pilot's control stick to supply the signal to the AFCS to maneuver the aircraft. Look for more information on this new AFCS system as more planes containing it are introduced into fleet operations during the next several years.

Inspection and Maintenance

Since the automatic pilot is considered a necessity in most present-day aircraft, instead of a luxury device as in earlier-day aircraft, maintenance problems have increased and acquired more importance. You will be required to perform maintenance at squadron and class C and D maintenance levels. In view of this, the Bureau of Aeronautics has implemented the following program to support fleet activities in maintaining flight control equipment presently installed in or planned for naval aircraft.

1. Provide line maintenance testers to enable squadron personnel to analyze the qualitative condition of the units while installed in the aircraft and determine the malfunctioning units requiring replacement.

2. Provide bench test kits to C and D level maintenance activities to completely facilitate testing and repair, as required, of all units or sets. Bench test kits will either be a complete system mockup with master junction box or test panel, or will have suitable signal simulators and test equipment to perform a functional check prior to installation of all system units. Gyros, accelerometers, indicators and all hermetically sealed instruments not maintainable at maintenance level will have functional test provisions provided.

3. Provision these systems to reflect procurement of all plug-in units and parts usable at C and D levels of maintenance. Tabulation of items obtainable will be published in individual allowance lists, Section X series.

4. Require preparation of *Handbooks of Operation and Service Instructions* according to a combination of specifications MIL-H-6757A (ASG) and MIL-H-5474A, with waivers to provide the most practical handbooks for maintenance activities. Handbooks will list and detail proper checkout procedures utilizing line maintenance and bench test equipment.

It is intended that the foregoing provisions, along with proper training, will completely cover all maintenance requirements and enable personnel to maintain fleet readiness of automatic flight control systems.

QUIZ

1. The altitude controller used in AFCS systems provides
    a. pitch stabilization
    b. a reference altitude for the human pilot
    c. a reference altitude for air traffic control
    d. a fixed altitude reference for automatic pilot operation

2. The amplitude and direction of a given yaw rate gyro signal is
    a. dependent only on the direction of yaw
    b. unaffected by the rate of turn in a yaw
    c. detected, amplified, and routed to the rudder servo
    d. dependent on the rate of turn and direction of a yaw

3. In the yaw damper system, the error signal is originated by a/an
    a. aneroid diaphragm
    b. rate generator
    c. rate gyro
    d. control transformer

4. The purpose of the hold button in the AFCS system is to hold the
    a. autopilot out of engagement before warmup
    b. aircraft in an attitude selected through the control stick
    c. aircraft at a selected altitude
    d. autopilot in engagement before warmup

5. The pitch synchronizing system in the pitch and yaw stabilization system
    a. provides a signal that cancels the pitch rate gyro signal when the aircraft is being maneuvered manually
    b. provides followup for the elevator channel
    c. consists of a rate generator and rate synchro
    d. consists of an open servo loop

6. Compass signals in the directional control circuit cause corrective action in the
    a. rudder channel only
    b. rudder and elevator channels
    c. aileron channel
    d. elevator channel only

7. The armature of the gain control unit will move to the left (fig. 10-7) when the aircraft's
   a. airspeed increases
   b. airspeed decreases
   c. airspeed decreases and the aircraft's altitude decreases
   d. altitude increases and the airspeed decreases

8. Vertical gyro units, as used in AFCS systems, detect
   a. roll about the aircraft's longitudinal axis, and yaw about the vertical axis
   b. yaw about the aircraft's vertical axis, and pitch about the lateral axis
   c. roll about the aircraft's lateral axis, and pitch about the longitudinal axis
   d. roll about the aircraft's longitudinal axis, and pitch about the lateral axis

9. The direction in which the potentiometer arm moves within the airstream direction detector is determined by the
   a. aircraft's airspeed
   b. barometric pressure
   c. difference of air pressures on the paddle chamber sides
   d. the sums of air pressures on the paddle chamber sides

10. The vertical gyro pendulum erecting system utilizes
   a. gravity and momentum for reference
   b. the gyro mass for reference
   c. the earth's north pole for reference
   d. the earth's vertical axis for reference

11. The airstream direction detector in the pitch and yaw stabilization systems provides
   a. yaw damping at high speeds
   b. yaw damping at slow speeds
   c. airspeed indication at slow speeds
   d. up elevator when maneuvering the aircraft

12. The roll synchro generated output signal in the vertical gyro unit is proportional to the difference between the
   a. gyro attitude and the roll synchro rotor
   b. gyro attitude and the airframe attitude
   c. airframe attitude and the roll synchro stator
   d. gyro attitude and the roll erection pendulum stator

13. The yaw damper system detects any
    a. sudden movement of the aircraft
    b. sudden movement about the lateral axis of the aircraft
    c. sudden movement about the vertical axis of the aircraft
    d. change in attitude
14. In an automatic pilot system for high-speed aircraft, the directional signal from the compass system is fed into the
    a. rudder channel
    b. rudder and aileron channel
    c. aileron channel
    d. rudder and elevator channel
15. When in full automatic pilot mode, coordinated turns are assured at all speeds due to the
    a. pendulum control unit
    b. compass system
    c. vertical gyro unit
    d. stick controller
16. The pitch and yaw stabilization system provides stabilization of the aircraft
    a. at all times when in flight
    b. when in flight and traveling only at high speeds
    c. when the wing slots are down
    d. when in flight and the wing slots are up
17. The gain control unit used in the pitch and yaw stabilization system
    a. compensates for attitude and airspeed
    b. compensates for altitude and airspeed
    c. is controlled by ram air pressure
    d. is controlled by barometric pressure

CHAPTER 11

PRESSURIZATION AND CABIN TEMPERATURE CONTROL

Chapter 6 of the Navy Training Course, *Aviation Structural Mechanic 3 & 2,* Vol. 2, NavPers 10326, presents information concerning aircraft pressurization and air conditioning systems. The chapter is concerned primarily with the mechanical aspects of the various components of these systems. As an AE, you are concerned primarily with the electrical aspects of these systems. However, the information contained in *AM 3 & 2,* chapter 6, can be of much help in enabling you to perform your electrical work better and you should become familiar with it.

Most present day aircraft require cabin or cockpit air pressure and temperature control because of the extreme speeds and altitudes at which they operate. The reason for cabin pressurization is to maintain an altitude pressure level within the cabin, below the outside altitude pressure at which the aircraft is flying.

The system which maintains cabin air temperature to meet the requirements for pilot efficiency is the air conditioning system. The sources of heat which make cabin air conditioning necessary are: (1) ram-air temperature, (2) engine heat, (3) solar heat, (4) electrical heat, and (5) body heat (personal).

Ram-air temperature is the frictional temperature created by ram compression on the skin surface of an aircraft. This factor becomes serious only at extreme air speeds. For example, if an aircraft were flying at

45,000 feet, at a speed of 1,200 m.p.h., the ram-air temperature would be about 200° F. on some parts of the aircraft. This extreme temperature plus the heat from the other sources would cause the cockpit temperature to rise to about 190° F. The maximum temperature that a pilot can stand and still maintain physical and mental efficiency is about 110° F. Prolonged exposure to a temperature greater than 110° F. will seriously impair his mental and physical condition.

It will be necessary that you become familiar with some terms and definitions to fully understand the operating principles of pressurization and air conditioning systems. These are as follows:

1. ABSOLUTE PRESSURE—pressure measured along a scale which has zero value at a complete vacuum.

2. ABSOLUTE TEMPERATURE—temperature measured along a scale which has zero value at that point where there is no molecular motion (-273.1° C. or -459.6° F.).

3. ADIABATIC—a word meaning no transfer of heat. The adiabatic principle is one in which no heat is transferred to or from the working substance and any outside source.

4. AIRPLANE ALTITUDE—the actual height above sea level at which an airplane is flying.

5. AMBIENT TEMPERATURE—the temperature in the area immediately surrounding the object under discussion.

6. AMBIENT PRESSURE—the pressure in the area immediately surrounding the object under discussion.

7. STANDARD BAROMETRIC PRESSURE—the weight of gases in the atmosphere sufficient to hold up a column of mercury 760 millimeters high (approximately 30 inches)—at sea level (14.7 p.s.i.). This pressure decreases with altitude on a logarithmic scale.

8. COCKPIT ALTITUDE—used to express cockpit pressure in terms of equivalent altitude above sea level.

9. DIFFERENTIAL PRESSURE—the difference in pressure between the pressure acting on one side of a wall and the pressure acting on the other side of the wall. In aircraft air conditioning and pressurizing systems, it is the difference between cabin pressure and atmospheric pressure.

10. **GAGE PRESSURE**—a measure of the pressure in a vessel, container, or line, as compared to ambient pressure.

11. **RAM-AIR TEMPERATURE RISE**—the increase in temperature created by the ram compression on the surface of an aircraft traveling at a high rate of speed through the atmosphere. The rate of increase is proportional to the square of the speed of the object.

12. **TEMPERATURE SCALES**—

a. **CENTIGRADE**—a heat measurement in which 0° C. represents the freezing point of water and 100° C. is equivalent to the boiling point at sea level.

b. **FAHRENHEIT**—a heat measurement in which 32° F. represents the freezing point of water and 212° F. is equivalent to the boiling point at sea level.

There are five basic requirements for cabin pressurizing and air conditioning systems:

1. A pressurized area of the aircraft, usually the cockpit or cabin, designed to withstand the specified pressure differential.
2. An adequate source of compressed air.
3. A means of controlling the cabin pressure by regulating the outflow of air from the cabin.
4. A means of dumping all regulated air from the cabin and provisions for obtaining fresh air.
5. A means of conditioning (in most cases cooling) the compressed air before it enters the cabin.

Requirement 1, the design of the cabin to withstand the pressure differential and hold leakage of air within the limits of the pressurization system, is primarily an airframe engineering and manufacturing problem. Requirement 2, an adequate air supply, is provided by a separate air compressor or air from the compressor section of the aircraft's jet engine. Requirement 3, control of the outflow of air from the cabin, is provided by the cabin pressure regulator. Requirement 4, rapid expulsion of air that may be contaminated, is done through the cabin dump valve. This may be operated by either a lever or an electrical switch. Simultaneously, fresh ram air may be brought into the cabin through the ram-air valve. Requirement 5, a means of conditioning (cooling) air, is provided by an aircraft refrigerator unit.

In addition to the components just discussed, various valves, controls, and allied units are necessary to complete a cabin pressurizing and air conditioning system.

When auxiliary systems such as windshield anti-icing, canopy defrosting, pressurized canopy sealing, pressurized fuel tanks, and pressurized hydraulic tanks are required, additional shutoff valves and control units are necessary.

Figure 11-1 shows a typical cockpit pressurizing and air conditioning system.

PRESSURE AND HEAT SOURCE

Hot high-pressure air comes from a compressor, such as a supercharger, or the compressor section of a jet engine. The temperature of the bleed air delivered to the pressurizing and air conditioning system will be 300° to 800° F. The pressure of this air will be from 75 to 250 p.s.i.

The temperature of this air being delivered to the cockpit must be cooled to the point where the pilot's efficiency is not impaired. Normally, this is from 60° F. to 80° F., depending on the pilot himself. In addition to reducing the temperature, the pressure of the air is also reduced. Atmospheric pressure at sea level is approximately 14.7 p.s.i. Cockpit pressure is maintained as near as is practical to sea level pressure. As altitude increases, the atmospheric pressure decreases. Modern aircraft have traveled at altitudes where the atmospheric pressure is only 1 p.s.i.

If an unprotected pilot were exposed to this air pressure, he would be seriously injured or killed. It is mandatory that all aircraft having an operating altitude of 35,000 feet or greater be equipped with pressurizing equipment.

Pressure regulating equipment will be covered later in this chapter.

Primary Heat Exchanger

The primary heat exchanger (fig. 11-1) is the first stage of cooling the hot air coming from the compressor.

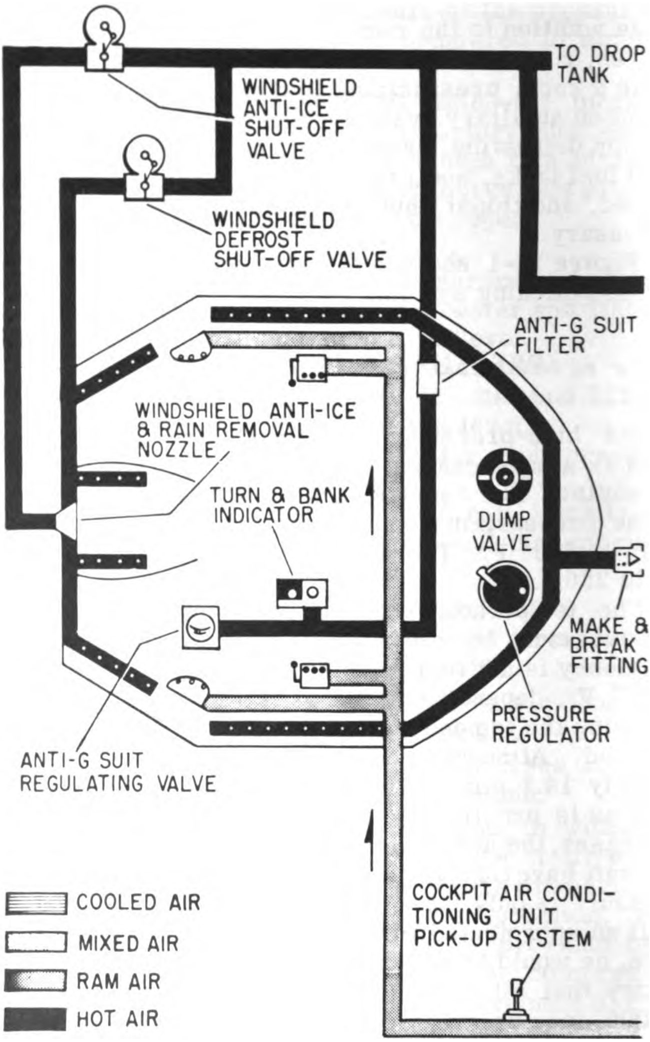


Figure 11-1.—Typical cockpit pressurizing and air conditioning system schematic.

It is located downstream from the compressor and is similar to an automobile radiator. The hot air travels through metal cores in the same manner as water in the automobile radiator travels through the radiator core.

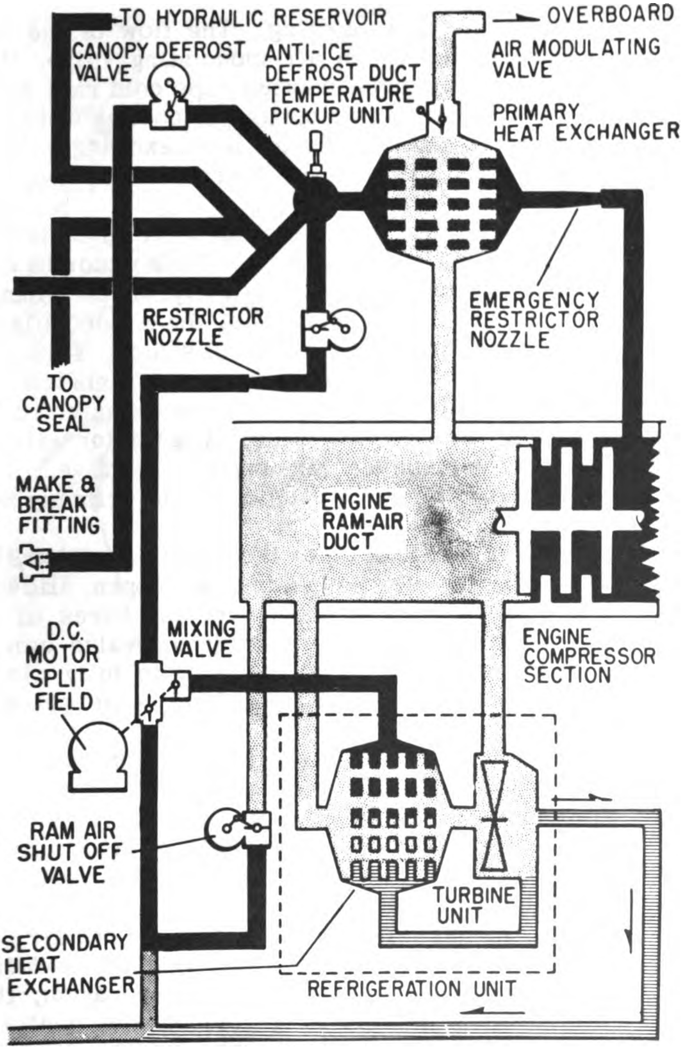


Figure 11-1.—Typical cockpit pressurizing and air conditioning system schematic—Continued.

Cold ram air passes over the primary heat exchanger core in much the same manner as air is pulled through the automobile radiator by the fan.

This is called air-to-air cooling. The flow of the cold ram air is regulated by an air-modulating valve. With the valve in the fully open position, the cold ram air is not restricted. This allows maximum cooling of the hot air passing through the primary heat exchanger core. With the modulator valve closed, there will be no air-to-air cooling.

The position of the air-modulating valve is controlled by a d-c, split-field, electric motor. This motor is controlled either manually or automatically. In the manual mode, the pilot has direct control of the air-modulating valve through the temperature control switch. This control switch (cockpit air temperature) is labeled off, hotter, normal, colder. If the switch is actuated to the hotter position, the air-modulating valve motor will run in a direction to close the air-modulating valve. This allows less cold ram air to pass over the primary heat exchanger core.

If the switch is actuated to the colder position, the motor will drive the air-modulating valve open, allowing maximum cold ram air to pass over the cores of the primary heat exchanger. The modulating valve can be positioned any place from fully opened to fully closed depending on how long the switch is held in the selected position.

In the automatic mode, the air-modulating valve is controlled by a bridge and amplifier circuit. This automatic system has control of the modulating valve when the cockpit air temperature switch is placed in the normal position. Automatic control will be covered in more detail later in this chapter.

The primary heat exchanger will cool the hot air to a temperature of approximately 325° F., when the modulating valve is fully open. During normal operation, this air is sent through another stage (secondary heat exchanger) of cooling before it is used in the cockpit.

Secondary Heat Exchanger

The secondary heat exchanger is the next stage for cooling the warm air that leaves the primary heat exchanger. Figure 11-2 shows an aircraft refrigeration unit. This unit is a typical secondary heat exchanger.

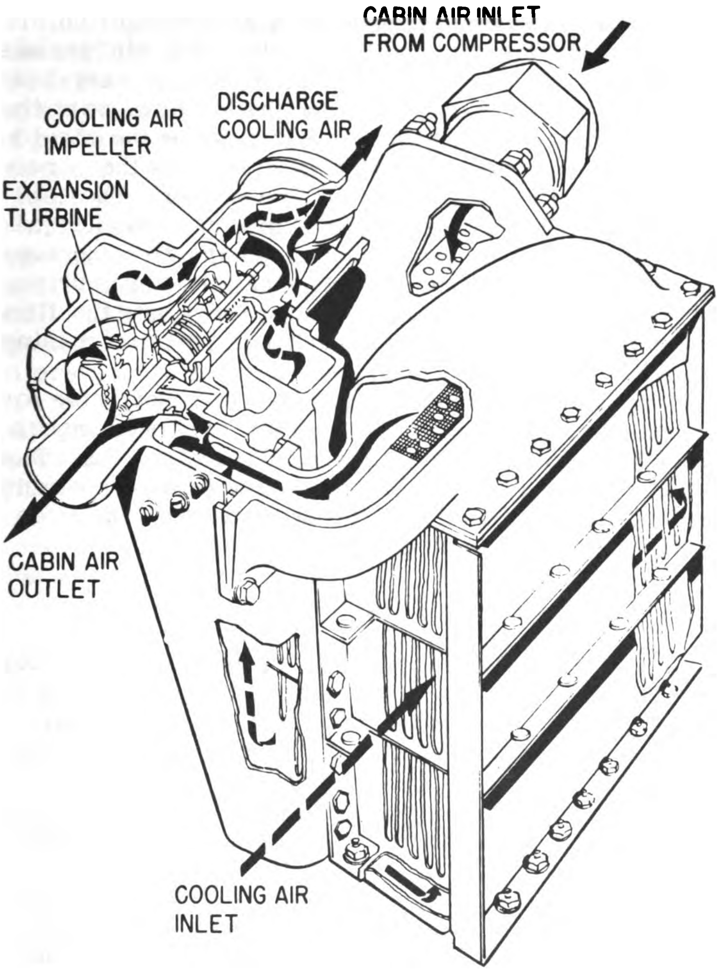


Figure 11-2.—Typical aircraft refrigeration unit.

Some installations use more than one primary heat exchanger. These primary exchangers operate on the principle of air-to-air cooling. The final stage of cooling will always employ the adiabatic principle. The adiabatic principle of operation is one in which no heat is transferred to or from a working substance. That is, the final cooling of cabin air is accomplished by means of rapid expansion, rather than exchange of heat.

The warm air from the primary heat exchanger enters the cabin air inlet (fig. 11-2). The inlet air passes through metal cores just as it did in the primary heat exchanger. At the same time, cooling air flows over the metal cores and again cools the cabin air by the air-to-air process. As the cooled cabin air leaves the cores, it is routed into an expansion turbine section. The cooling turbine operates on the principle of expanding air suddenly. This rapid expansion causes the air to become still cooler. The cooling air discharge impeller is driven by the expansion turbine. This impeller boosts the flow of cooling air through the heat exchanger, thus increasing the efficiency of the refrigeration unit.

The Aviation Structural Mechanic is responsible for the maintenance and installation of heat exchangers, turbines, ducting, and various mechanical valves. The Aviation Electrician will be required to troubleshoot and maintain the electrical controlling features of the pressurizing and air conditioning system.

Mixing Valve

The mixing valve is enclosed in an aluminum alloy housing and is actuated by an electric motor. This valve is a modulating type and serves as a means of proportioning the hot and cold air to the aircraft's cabin. (See fig. 11-1.) The valve has an inlet port and two outlet ports. It is connected into the system so that the hot compressed air is supplied to the inlet port of the valve. One of the outlet ports is connected to the inlet of the refrigeration unit. This is called the cold side of the valve because air from the port becomes cold air after it passes through the refrigeration unit. The other outlet port of the mixing valve is connected to a line which bypasses the refrigeration unit. This port is connected to the cabin air supply line. The mixing valve contains two butterfly valves that are mounted on a common shaft. One of these valves is in each outlet port. They are mechanically arranged so that when either is fully closed, the other is fully open. As the actuator is operated through its cycle, the closed side will begin to open and the open side will close a proportionate amount. In this manner, it is possible to proportion the hot compressed

air to or around the refrigeration unit without affecting the airflow through the system. The mixing valve is operated according to the demands of the cabin temperature system, resulting in its assuming an infinite number of positions between either extreme, thus controlling the temperature of the air delivered to the cabin within specified values.

The motor that actuates the valve is a split-field, d-c type motor, that is equipped with a magnetic brake. Contacts inside the motor housing break the circuit to the individual fields when the actuator is either in the fully opened or fully closed position. The reason for this is to prevent the motor being overloaded. If the actuator is in the fully closed position, the contact breaking the circuit to the motor field will complete a circuit to the modulating valve motor of the primary heat exchanger. This causes it to restrict the flow of ram air, thus allowing more hot air to reach the cockpit. This will be described in more detail when temperature control is discussed.

ELECTRONIC CABIN TEMPERATURE CONTROL SYSTEM

The operation of the electronic temperature control system is based primarily on the balanced bridge circuit principle. When any of the units which compose the "legs" of the bridge circuit changes resistance value due to a temperature change, the bridge circuit becomes unbalanced. An electric regulator receives an electrical signal as a result of this unbalance and amplifies this signal to effect the control of the primary modulating and mixing valve actuators.

In a typical application of the electronic temperature control system, three units are utilized. They are: (1) the electronic regulator; (2) the manual temperature selector, and (3) the cockpit temperature pickup (thermistor).

Figure 11-3 shows a simplified schematic diagram of an electronic temperature control system.

Cockpit Temperature Pickup Unit

The cockpit temperature pickup unit serves as the temperature sensing unit of the cockpit. This unit consists

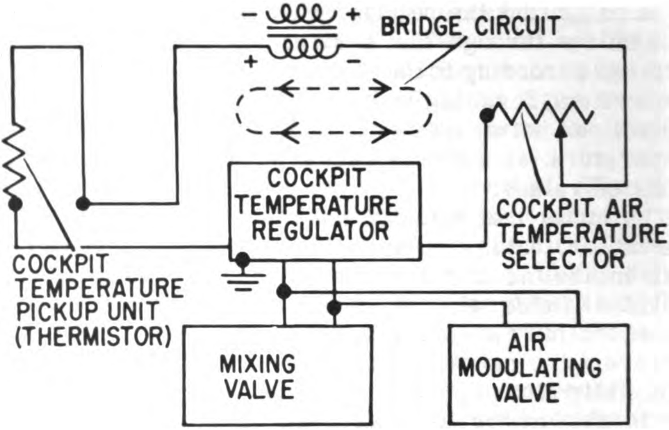


Figure 11-3.—Simplified schematic diagram of an electronic temperature control system.

of a resistor that is highly sensitive to temperature changes. The cockpit temperature pickup unit is usually located in the cockpit or cockpit air supply duct. As the temperature of the air supply changes, the resistance value of the pickup unit also changes, thus causing the voltage drop across the pickup to change. The cockpit temperature pickup is a thermistor-type unit. As the ambient temperature of the resistance bulb increases, the resistance of the bulb decreases.

Cockpit Air Temperature Selector

The air temperature selector (fig. 11-3) is a rheostat located in the cockpit and is controlled by the pilot. It permits selective temperature control by varying the effective temperature control point of the cockpit air temperature pickup unit. The selector is labeled cold and hot. No specific temperature division markings are on the control knob. The rheostat causes the cockpit temperature pickup unit to demand a specific supply air temperature and does not reflect the temperature that will exist in the cockpit at any given time.

Cockpit Air Temperature Control Regulator

The cockpit air temperature control regulator, in conjunction with the cockpit air temperature selector rheostat

and the cockpit air duct temperature pickup unit, automatically maintains the temperature of the air entering the cockpit at a preselected value. The cockpit temperature regulator is an electronic device with a temperature regulating range. In some installations this range may extend from as low as 32° F. to as high as 117° F.

The output of the regulator controls the position of the butterfly valves in the air-modulating and mixing valves, thus controlling the temperature of the inlet air to the cockpit.

Typical System Operation

Figure 11-4 shows an electrical schematic of a typical air temperature control system.

In most air temperature control systems, there will be one switch located in the cockpit to select the mode of temperature control. Usually, this switch (cockpit air temperature control switch) will have four positions—off, normal, hot, and cold. In the off position, the air temperature control system is inoperative. With the switch in the normal position, the air temperature control system is in the automatic mode. With the switch in either the hot or cold position, the air temperature control system is in the manual mode.

OFF POSITION.—With the cockpit air temperature switch in the off position, the pilot has no control of the cockpit air temperature.

The cockpit air temperature may become very hot or very cold, depending on the position of the butterfly valves of the mixing valve and air-modulating valves. Since these valves are actuated by d-c motors, it is possible that they were left in the full hot or full cold position when the system was last operated.

MANUAL MODE.—In the manual mode, the pilot can change the position of the butterfly valves by selecting hot or cold. This directs d-c current to the hot-field or cold-field winding of the actuator. When the pilot uses this mode, it will be necessary for him to place the control switch in the off position after the valves have traveled to a position at which the system is delivering the desired air temperature to the cockpit.

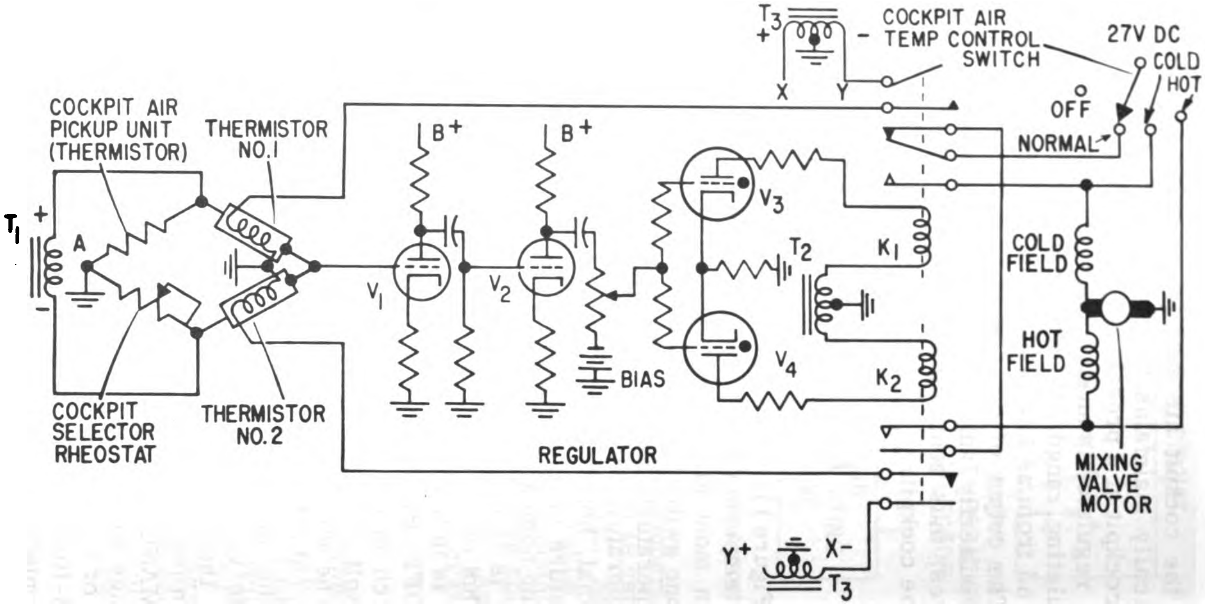


Figure 11-4.—Simplified schematic diagram of an air temperature control system.

AUTOMATIC MODE.—In the automatic mode, the control switch will be placed in the normal position. This allows the d-c current to be controlled by the regulator.

The cockpit selector rheostat and the cockpit air pickup unit (thermistor) determine the direction and amount of rotation of the mixing and modulating valves motors. This function is controlled in the cabin air temperature regulator. It can be seen (fig. 11-4) that the cockpit selector rheostat and the cockpit air pickup unit are connected into a bridge circuit which also includes two thermistors that are located in the regulator.

The bridge circuit is energized by an a-c source (*T*). If the resistance of the cockpit air pickup unit and the cockpit selector rheostat were equal, then points A and B would have no potential difference.

Note that points A and B are the signal reference points for *V*1 (grid and cathode). If the cockpit air temperature increases, the resistance value of the cockpit air temperature pickup unit decreases, since the flow of the air passes over the pickup unit. This decrease in resistance of the pickup unit causes the voltage drop across the pickup unit to decrease, resulting in a potential difference between points A and B.

This signal, which is impressed on the grid of *V*1, goes through two stages of voltage amplification (*V*1 and *V*2). The amplified signal is parallel to the grids of two thyratron tubes (*V*3 and *V*4). The thyratron tubes are used for signal-phase detection. For example, if the signal on the grid of *V*3 is in phase with the plate of *V*3, *V*3 will conduct, causing current to flow through the coil of relay 1 (*K*1). This will cause the contacts of *K*1 to be pulled down. One set of contacts completes a circuit for d-c current flow to the cold-field coil of the mixing valve motor. This directs more air through the refrigeration unit, thereby cooling the cockpit air temperature. At the same time, the remaining set of contacts of *K*1 completes a source of a-c power (*T*3) to the heating element of thermistor No. 1 of the bridge circuit. This causes the resistance of thermistor No. 1 of the bridge circuit to decrease. The resultant change in the voltage drop across thermistor No. 1 results in a balanced bridge across points A and B. This, in turn, causes relay (*K*1) to become deenergized, stopping the rotation of the mixing

valve motor. At this point, heater voltage is removed from thermistor No. 1 and it cools, thereby again unbalancing the bridge. This causes the mixing valve motor to drive farther towards the cool position allowing still more refrigerated air to enter the cabin. This cycling continues until the voltage drops across the cockpit pickup unit and the cockpit selector rheostat are equal.

Had the cabin air temperature been colder than the selected setting, the bridge would have become unbalanced in the opposite direction. This would have caused relay K2 in the regulator to become energized, thus energizing the hot-field coil of the mixing valve motor.

The bridge may also be unbalanced by another method. This is done by repositioning the cockpit selector rheostat. Again the mixing valve moves to regulate the temperature of the air until the bridge is rebalanced.

COCKPIT PRESSURIZING SYSTEM

The cockpit pressurizing system provides control of the pressurized air which is supplied to the cockpit by means of the air conditioning system ducts. This air is from the engine compressor section. A cockpit air pressure regulator maintains either of two manually selected cockpit air pressure schedules. These are referred to as combat schedule or normal schedule.

The first of these schedules (combat) consists of a nonpressurized cockpit from sea level to 10,000 feet and a constant 10,000-foot cockpit altitude pressure from an airplane altitude of 10,000 feet to 18,000 feet. The combat schedule also maintains a 2.75 p.s.i. cockpit differential at all altitudes above 18,000 feet.

The alternate schedule (normal) consists of a nonpressurized cockpit from sea level to 10,000 feet and a constant 10,000-foot cockpit altitude from an airplane altitude of 10,000 feet to 26,500 feet. This schedule also provides a 5 p.s.i. cockpit differential at all altitudes above 26,500 feet.

The cabin pressure regulator employs a solenoid valve. When this solenoid valve is energized with 27 volts d.c., it positions a metering valve and provides an alternate air pressure schedule of 5 p.s.i. differential pressure. With the solenoid deenergized, the metering

valve provides an air pressure schedule of 2.75 p.s.i. differential.

ADDITIONAL VALVES

If the cockpit air becomes contaminated or the pressurization system fails, a ram-air valve will allow ram air to enter the cockpit and leave by the dump valve. This action clears the cockpit of contaminated air. When the ram-air valve is opened, the normal compressor air supply is shut off by means of the system shutoff valve. Normally, these valves are operated electrically by a single switch in the cockpit, labeled RAM ENERGIZING. Refer to figure 11-1 for the location of these valves in a typical pressurizing and heating system.

ANTI-ICE AND DEFROST SYSTEM

The anti-ice and defrost system on most aircraft that employ the heating system and pressurization system described in this chapter will use the same air source. The anti-ice and defrost system consists of the following three systems—windshield anti-ice, windshield defrost, and windshield rain removal. Each receives its hot air supply from a common manifold. The manifold is kept at a set temperature by a regulating system similar to the cabin air temperature system. (Refer to fig. 11-1.)

QUIZ

1. Explosive decompression occurs when the cockpit air pressure is
   a. slowly dropped from 14.7 p.s.i. to about 2 p.s.i.
   b. instantly dropped from 14.7 p.s.i. to 10 p.s.i.
   c. instantly dropped from normal cabin pressure to outside pressure at 35,000 ft. altitude or above
   d. instantly dropped from normal cabin pressure to outside pressure at 12,000 ft. altitude or below

2. The primary air modulating valve controls the
   a. amount of compressed air to the pressurizing system
   b. pressure of the compressed air to the defrosting system
   c. pressure of the compressed air to the air conditioning system
   d. temperature of the air from the primary heat exchanger
3. When the ram-air switch is placed in the ram-air position, the
   a. cockpit remains on the 2.75 pressurization schedule
   b. system shutoff valve opens
   c. dump valve closes
   d. canopy seal deflates
4. Which of the following does not contribute to cabin temperature?
   a. Engine heat
   b. Solar heat
   c. Adiabatic heat
   d. Body heat
5. Ram-air temperature is caused by
   a. plenum pressure in the intake
   b. motion of air across the skin surface
   c. speed of the exhaust gases
   d. heat of the air in the pitot tube
6. In the secondary heat exchanger the
   a. cooling air impeller and the expansion turbine are on a common shaft
   b. cooling air impeller and the expansion turbine are on separate shafts
   c. cooling air impeller boosts the flow of air to the expansion turbine
   d. adiabatic principle is not used
7. The mixing valve
   a. shuts off the flow of air to the cabin
   b. allows hot air to be routed only to the secondary heat exchanger
   c. allows hot air to be routed to the defrosters
   d. apportions hot and cold air to the cabin
8. The electronic temperature control bridge has
   a. two variable resistors and two fixed resistors
   b. two variable resistors and two thermistors
   c. four variable resistors in a balanced bridge circuit
   d. four variable resistors in an unbalanced bridge circuit

9. The anti-ice and defrost system is controlled by
   a. the mixing valve
   b. the pressure regulator
   c. the cockpit air conditioning unit pickup
   d. a separate temperature control system

10. Which of the following describes cockpit differential pressure?
    a. The difference between atmospheric and cockpit pressure.
    b. The sum of atmospheric and cockpit pressure.
    c. The difference between barometric and absolute pressure.
    d. The difference between cockpit pressure and sea level pressure.

11. The cockpit combat pressure differential is regulated at
    a. 5 p.s.i. differential to 10,000 ft.
    b. 2.75 p.s.i. differential to 18,000 ft.
    c. 2.75 p.s.i. differential above 18,000 ft.
    d. 5 p.s.i. differential above 18,000 ft.

12. The cabin pressure is determined by the
    a. system shutoff valve
    b. air flow venturi
    c. cabin pressure regulator
    d. cabin pressure regulator and cooling air bypass valve

13. The pilot places the selector switch in the hot position until full hot is reached. He then places the switch in the normal position. What will happen to the cabin temperature?
    a. The temperature will be controlled in the automatic mode.
    b. The temperature will go to full cold.
    c. The temperature will stay at full hot.
    d. The temperature will start to decrease.

14. After changing the cockpit temperature manually, the selector switch should be placed in the
    a. hot position
    b. cold position
    c. normal position
    d. off position

15. The opening of the ram-air valve used in aircraft cabin pressurization systems will
   a. allow outside air to dissipate the refrigerator unit heat
   b. proportion ram-air with the compressor air supply
   c. automatically stop the refrigeration unit's turbine
   d. clear cockpit of contaminated air
16. The heating element of thermistor No. 1 becomes hot when
   a. *K2* is energized
   b. *V4* is conducting
   c. *V3* is conducting
   d. air temperature control switch is in the HOT position
17. A pressurizing air conditioning system must utilize
   a. a source of compressed air
   b. a means of controlling the exhaust
   c. a means of cooling the inlet air
   d. all of the above
18. The heat source for a cabin air conditioning and pressurizing system is
   a. any source of hot compressed air
   b. a gasoline heater only
   c. an electric heater only
   d. solar heat
19. Tubes *V1* and *V2* of the regulator unit (fig. 11-4) are
   a. voltage amplifiers
   b. signal discriminators
   c. in parallel
   d. power amplifiers
20. Relay *K2* of the regulator unit controls the current to
   a. *V4*
   b. thermistor No. 1
   c. the hot field of the mixing valve motor
   d. the cold field of the mixing valve motor

CHAPTER 12

PROPELLER SYNCHRONIZATION

The jet aircraft has come into wide use in naval aviation during the past several years. During this time the propeller-driven reciprocating engine aircraft has been substantially pushed into the background by its newer and faster successor. However, there remains a number of types of missions for which the jet is poorly suited. Among these are long-range patrol flights, antisubmarine warfare, and radar picket work. Propeller-driven aircraft are better suited than jets to perform these missions. The R7V, WV-2, S2F, P2V, and P5M are propeller-driven planes now being used by the Navy. All of these aircraft use reversing-type hydromatic propellers which are equipped with a propeller synchronizing system.

A reversing hydromatic propeller is one in which provision is made for obtaining a negative blade angle. With a negative angle, a propeller produces a thrust which acts in the opposite direction to that normally produced by the propeller in flight. Negative thrust is useful in landing large multiengine aircraft on short runways.

The propeller synchronizing system provides a flexible means of controlling and synchronizing engine speed. Among the features provided are: (1) limited range synchronization, (2) positive positioning of propeller governors against the high r.p.m. stops at takeoff, (3) speed adjustment of all engines throughout the entire operating range by a single master control lever, and (4) separate adjustment of each propeller governor by individual pitch control switches.

This chapter is written primarily to explain the electrical characteristics of the synchronizing system of the hydromatic propeller. It will be necessary at times to go into the detailed operation of the hydromatic propeller system components. The mechanical operation of these components functions directly with the electrical circuit. If you are not familiar with the essentials of aircraft propeller operation, it is suggested you become familiar with them. A suggested reference is the Navy Training Course, *Aviation Machinist's Mate 3,* NavPers 10338, chapter 12.

The hydromatic propeller is a constant speed type in which adjustments of the blade angle can be accomplished during engine operation, either in the air or on the ground. Blade angle change is controlled by means of a mechanical-hydraulic system which is regulated by the action of a governor.

DOUBLE-ACTING TYPE GOVERNOR

The engine-driven governor is a constant speed control unit of the flyweight type. It consists of a gear pump, a pilot valve, and a relief valve system. The gear pump boosts the engine oil pressure to the value required for propeller operation. The pilot valve is actuated by the flyweights and controls the flow of oil through the governor. The relief valve system regulates the operating pressure in the governor.

The propeller governor provides the required oil pressure on the propeller pistons to maintain a desired propeller pitch. The r.p.m. at which the propeller operates is determined by the setting of the speed control in the governor head. The governor head is mounted on top of the governor body. Figure 12-1 shows a typical governor assembly.

The governor head consists of a permanent magnet rotor, three-phase windings, and mechanical stops. The three-phase windings receive a changing d-c polarity current which controls the movement of the permanent magnet rotor. The rotor is allowed to rotate clockwise or counterclockwise, depending on the polarity of the d-c currents impressed on the three-phase windings. The rotor is connected to a rack in the governor body. This rack, when moved by the rotor, will cause the speeder spring in the

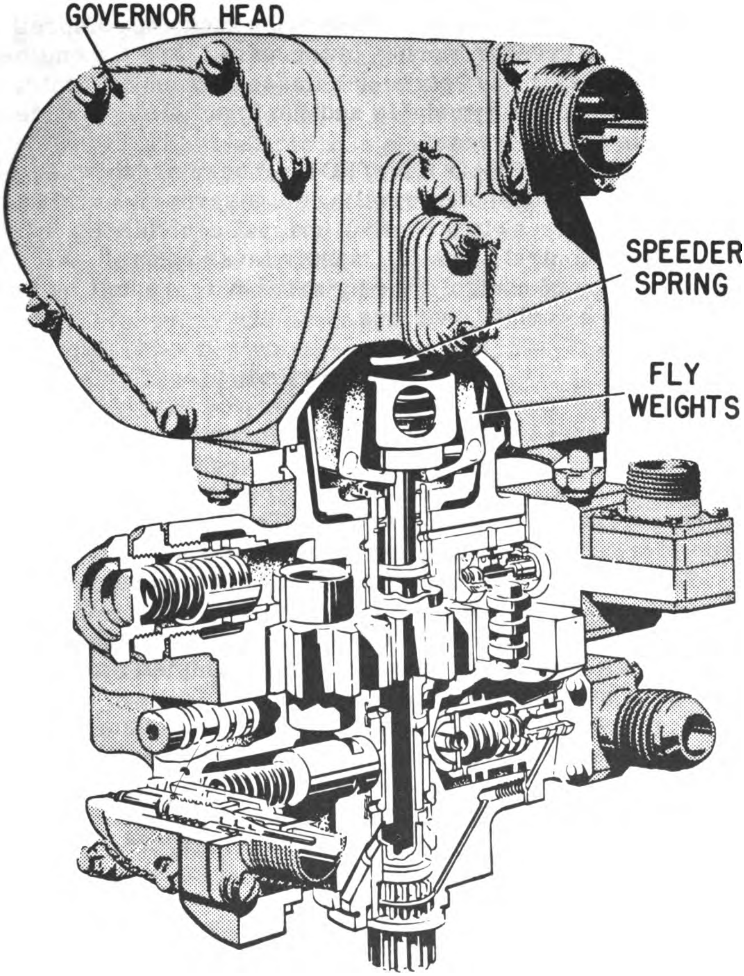


Figure 12-1.—Double-acting governor and governor head.

governor to become more compressed or less compressed. When the governor head raises the rack, the compression in the speeder spring is decreased, and the engine r.p.m. necessary to establish balance between the centrifugal force of the flyweights and the force of the speeder spring is decreased. The onspeed condition is established when a state of equilibrium exists between two forces.

When the governor head lowers the rack, the compression in the speeder spring is increased, and the engine r.p.m. necessary to establish balance between the centrifugal force of the flyweights and the force of the speeder spring is also increased.

GOVERNOR HEAD CONTROL.—There are three separate ways (modes) of controlling the governor head. They are: (1) toggle switch control (manual control), (2) synchronizer control, and (3) master lever control. All of these modes of control are originated in the cockpit by the pilot setting certain switches.

Manual Control

The manual control mode of the governor head utilizes the following components:

1. A double-pole, double-throw toggle switch for each governor head to be controlled. These toggle switches are located in the cockpit on a control stand.
2. A commutator switch assembly. This assembly is located inside the synchronizer unit.
3. Two manual override relays. Each relay has four armatures (poles), and each armature completes a circuit to one of two circuits.

Figure 12-2 shows a schematic diagram of the manual control mode.

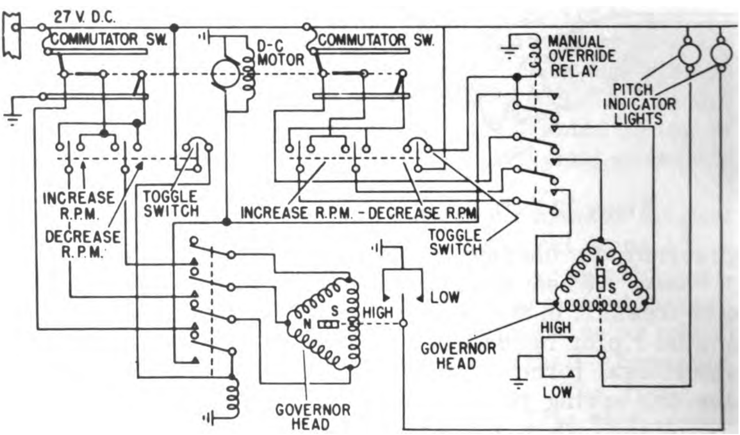


Figure 12-2.—Governor head manual control schematic diagram.

The toggle switch receives 27 volts from the d-c bus. Selecting an increase or decrease r.p.m. position on the switch causes a manual override relay to be energized. The manual override relay has four armatures (poles). One of these armatures completes a circuit to the d-c motor of the commutator switch. Each of the other three armatures completes a circuit between a commutator switch and the governor head.

The commutator switches are connected to a common shaft of the d-c motor. Each commutator switch has three armatures, which are arranged so that one armature will have a positive d-c voltage applied to it, the other a negative d-c voltage, and the third zero voltage. As the commutator motor rotates, the armatures will also rotate, causing the voltage polarity to change. One complete cycle will cause each armature to have had three different polarities—positive, negative, and zero. This changing d-c polarity appears across the three windings of the governor head, resulting in a rotating field. This rotating field causes the permanent magnet rotor of the governor heads to rotate.

The governor head rotor can be made to rotate in the opposite direction by changing any two leads of the commutator switch. This is done by actuating the toggle switch in the opposite direction. The commutator motor will still turn in the same direction due to a jumper wire on the toggle switch.

Each toggle switch controls one governor head. These heads may be controlled one at a time, or all may be controlled at the same time. When the governor head has reached the high r.p.m. or low r.p.m. mechanical stops, a ground circuit is completed to a pitch indicator light in the cockpit.

Synchronizer Control

The synchronizer control mode utilizes the aircraft's tachometer generators for sensing difference of engine r.p.m. between the master engine and one or more slaved engines. While in the synchronizer control mode, the system controls the slaved engine or engines governor head. The master engine is used for r.p.m. reference. This is accomplished by the following components in the

synchronizer unit: (1) differential motor, (2) synchronizer commutator switch, (3) master engine switching relay, (4) manual override relay, and (5) a synchronizer limiter.

The output of the master engine tachometer generator is connected to one of the two mechanically linked synchronous motors in the differential motor unit. The output of the slaved engine tachometer generator is connected to the other mechanically linked differential motor. These motors and their gear trains are linked in such a manner that no shaft rotation to operate the commutator switch results unless the motor speeds are different. The shaft rotation starts with motor speed differences caused by an increase or decrease of the frequency of the slaved engine tachometer generator relative to the frequency of the master engine tachometer generator. In this application the mechanical differential assembly drives the commutator switch to energize the slaved engine governor head in the direction required to synchronize the engines.

A mechanical limiting device of the mechanical differential assembly limits the synchronizing to approximately three percent of the master engine r.p.m. Thus, an abnormal increase or decrease in the r.p.m. of the master engine or even failure of the master engine cannot cause the slaved engine r.p.m. to change beyond this limit. A torsion spring device recenters the limiting unit each time the resynchronize button on the control stand is pressed.

Figure 12-3 shows a schematic diagram of the synchronizer control mode.

The synchronizing control mode is usually used after the engines have been manually synchronized by the toggle switch mode. The pilot must first close the master lever and synchronizer control switch in the cockpit. This allows the engine tachometer generators and the differential motors to be connected to each other, and also connects the synchronizer commutator switch to the slaved engine governor head.

The toggle switch control mode will override the synchronizer control mode any time the pilot toggles the toggle switch.

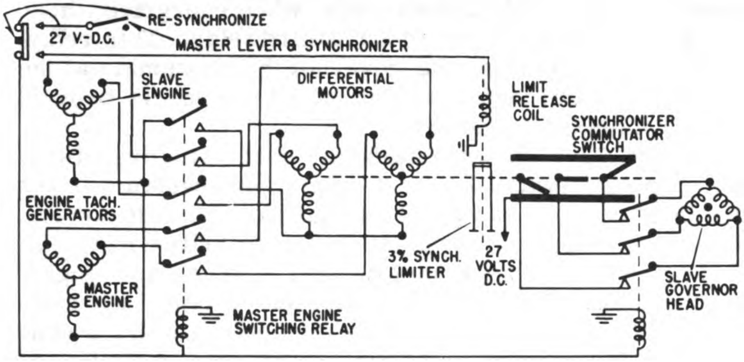


Figure 12-3.—Synchronizer control mode schematic diagram.

Master Lever Control

The master lever control mode (blue section of fig. 12-4) allows both engines to be controlled simultaneously by one lever movement. A lever located in the cockpit is connected through a cable to a pulley arrangement on the synchronizer unit.

The pulley is connected to an off-seeking, reversible, followup switch. This switch energizes one of two relays, which determines the direction the master motor of the master lever commutator switch will rotate. The master motor serves two functions: (1) to drive the off-seeking switch back to the null (off) position, and (2) to drive the master lever commutator switch. The master lever commutator is designed like the other commutator switches used in this system. It supplies a changing d-c polarity to both slaved and master governor heads, resulting in both engines changing their r.p.m. simultaneously.

The speed settings are proportional to the master lever movement. Any time the lever in the cockpit is advanced to takeoff position, both governors are set to their positive high r.p.m. stops, and the synchronizing feature is cut out so that failure of the master engine on takeoff will have no effect upon the slaved engine. This is accomplished by three takeoff relays.

These takeoff relays are controlled by the high- and low-limit switches of the governor heads. When the governor head high-limit switch closes, it completes a

ground for two of the three relays. When energized, these two relays apply d-c power to the third relay. This relay, in turn, assures that the governor heads remain at the high r.p.m. settings until the master lever is brought back from takeoff position.

Figure 12-4 shows a complete schematic diagram of the propeller synchronizer system. This system utilizes the three modes of operation that have been described. When studying these circuits refer to the written material.

Figure 12-5 shows an exploded view of a two-engine synchronizer. The preceding material in this chapter explained the operation of a two-engine synchronizing system. A four-engine synchronizing system is similar to the two-engine system, except for additional relays, differential motors, and commutator switches.

For complete information on installation, service inspection, maintenance, and lubrication of the hydromatic propeller synchronizing system refer to the *Handbook of Operation and Service Instructions*, AN 03-20CC-30, and the *Handbook of Overhaul Instructions, Synchronizers*, AN 03-20CE-1.

In addition to maintaining the synchronizing system, the AE will be called on to aid the AD with troubleshooting the feathering, unfeathering, reversing, and unreversing systems of the hydromatic propeller system.

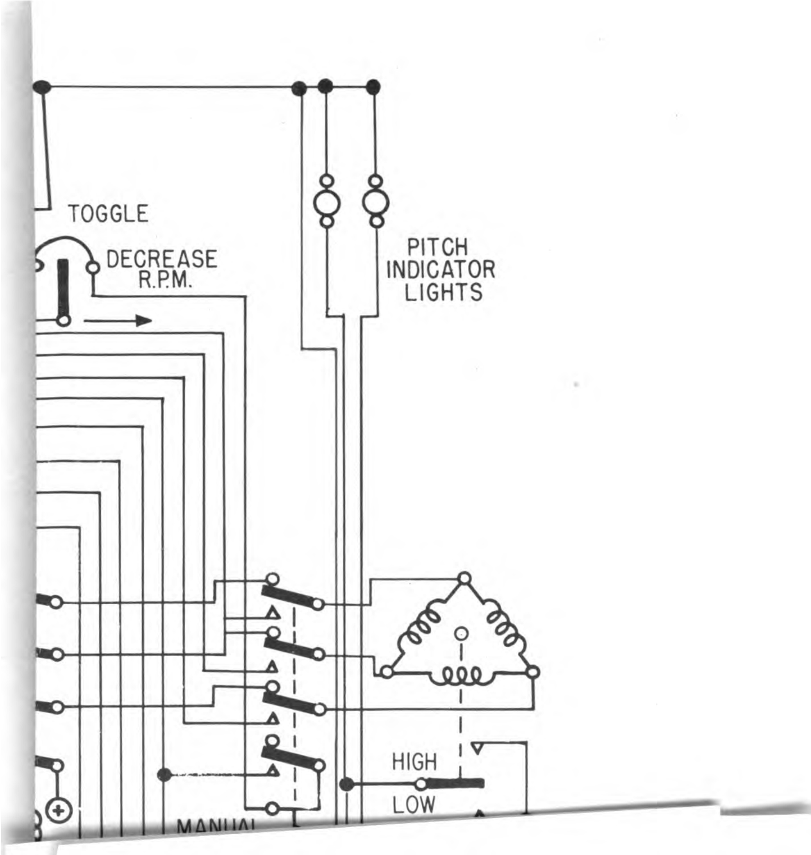
DOUBLE-ACTING GOVERNOR CONTROL

Feathering Operation

The feathering circuit contains the following components: a feathering switch, a pressure switch, one two-pole relay, two blade switches, and a feathering pump.

The feathering switch, as illustrated in figure 12-6, is a double-throw, neutral-off type switch with a holding coil that acts when the button is pushed in. The button must be held out manually. Push in to feather, and pull out to unfeather. One switch is required for each propeller, and it is mounted in the cockpit to permit quick operation.

A pressure switch is located within the propeller governor. It is normally closed and completes a ground for the holding coil of the feathering switch. When the propeller blades reach full feather, the oil pressure within


TOGGLE
DECREASE R.P.M.
PITCH INDICATOR LIGHTS
HIGH
LOW
MANUAL

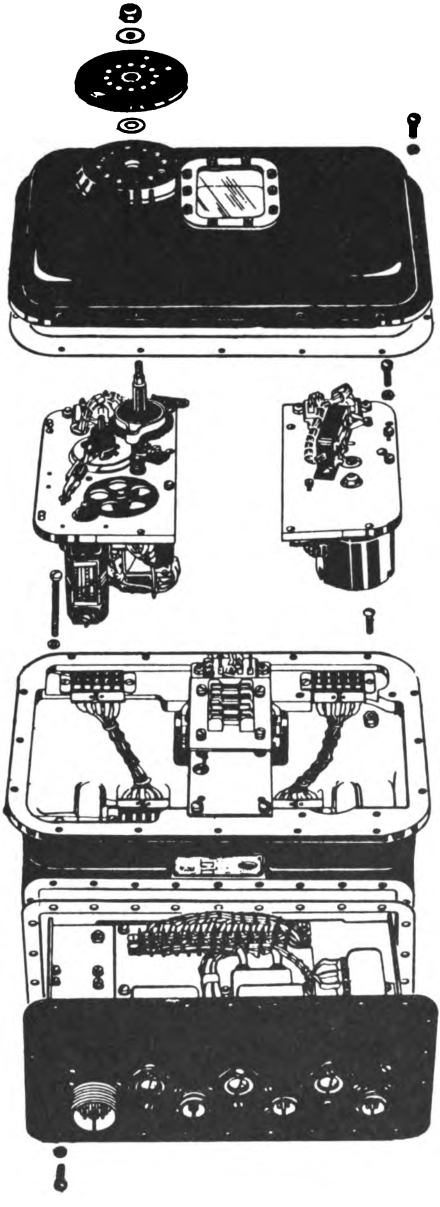


Figure 12-5.—Two-engine synchronizer.

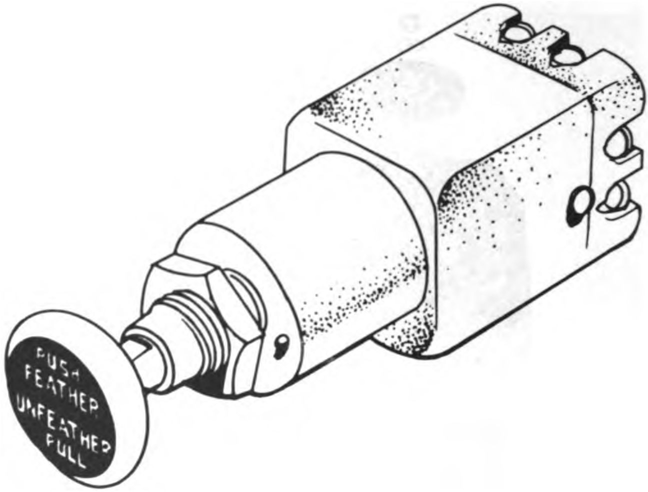


Figure 12-6.—Feather-unfeather switch.

the propeller dome builds up, causing the pressure switch to open, thus breaking the ground for the feathering switch holding coil.

The two blade switches are single-pole, cam-actuated. One is located on the No. 1 blade, and the other located on the No. 3 blade. The No. 3 blade switch is the only one used in the feathering operation. When the propeller blades reach full-feather position, the No. 3 blade switch becomes open, thus breaking a ground for relay *L*2. (See fig. 12-7.)

This relay completes a ground for the feathering switch holding coil. When the propeller blades reach full-feather position, relay *L*2 becomes deenergized, thus breaking the ground for the feathering switch holding coil.

The feathering pump is a motor driven gear type. A spring-loaded relief valve is adjusted to maintain oil pressure at the discharge port at 1,600 to 1,650 p.s.i. The motor is a 24-volt, series-wound, intermittent-duty type. The feathering pump is controlled by the feathering switch.

Figure 12-7 shows an electrical schematic diagram of the feathering system used on naval aircraft.

The complete sequence of operation of the feathering circuit (fig. 12-7) is as follows:

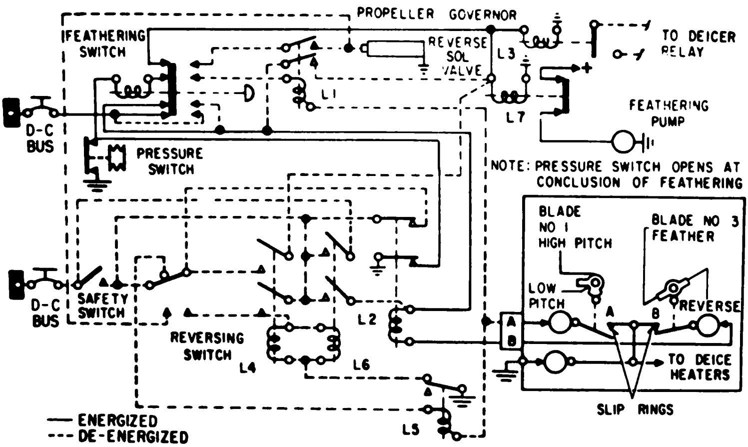


Figure 12-7.—Feathering circuit schematic diagram.

The pilot pushes in on the feathering switch button. This allows d-c current to flow through the feathering switch holding coil, completing a ground through the pressure switch or through the closed contacts of relay *L*2. Relay *L*2 also receives current from the feathering switch, completing its ground through the No. 3 blade switch. Thus, there are two ground circuits for the feathering switch holding coil. One of these is through the pressure switch, and the other is through the closed contacts of relay *L*2. The reason for this double ground is to assure that the propeller reaches full feather before allowing the feathering switch to be released.

The feathering switch also supplies power to relays *L*3 and *L*7. Relay *L*7 connects the feathering pump motor to a d-c source. The turning of the motor causes the propeller blades to move towards the full-feather position. Relay *L*3 automatically disconnects power to the propeller de-icer circuit. If the de-icer circuits and the feathering circuits were permitted to operate at the same time, there would be an excessive amount of current drawn from the d-c generator system.

When the propeller blades reach full-feather, the No. 3 blade switch will be actuated by a cam, causing its contacts to open. Following this, the pressure within the propeller dome will build up, causing the pressure switch

to open. When these ground circuits are open, the feathering switch becomes deenergized. This, in turn, deenergizes relay $L7$ and energizes relay $L3$. This action causes the feathering pump motor to stop turning and energizes the de-icer bus.

Unfeathering Operation

An additional component, the reverse solenoid valve, which is not used during the feathering operation, is used during unfeathering. This valve is located in the propeller governor. When energized with d-c current, it permits the high-pressure oil to flow in the propeller piston in the opposite direction as it did during the feathering operation. This causes the propeller piston to move toward the decrease pitch position.

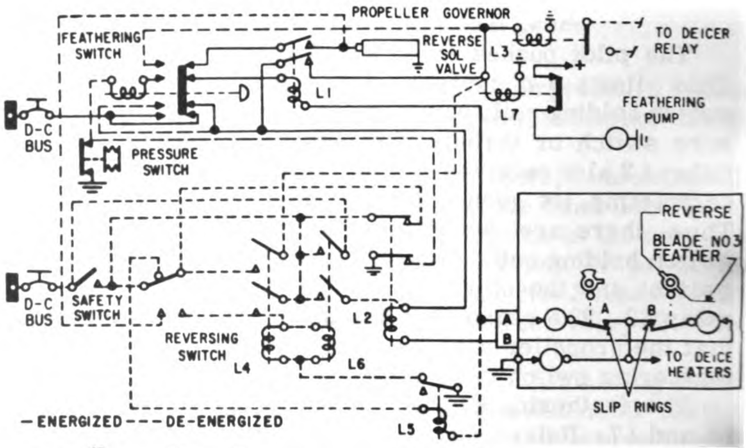


Figure 12-8.—Propeller unfeathering schematic diagram.

The complete sequence of operation of the unfeathering circuit (fig. 12-8) is as follows:

The pilot pulls out the feathering switch button; this supplies d-c current to the double-pole relay $L1$. The ground for this relay is completed through the No. 1 blade switch. This blade switch is in the closed position when the propeller is feathered.

The double-pole contacts of relay $L1$ supply d-c current to the reverse solenoid valve (relays $L7$ and $L3$).

Relay $L7$ connects d-c current to the feathering pump motor; relay $L3$ disconnects the propeller de-icer circuit.

As the feathering pump motor operates, it is supplying high-pressure oil through the reverse solenoid valve in a direction which causes the propeller blades to unfeather. When the propeller blades reach the low pitch position, the No. 1 blade switch is actuated by a cam. This opens the switch contacts allowing relay $L1$ to become deenergized, which, in turn, removes the d-c current from the reverse solenoid and relay $L7$. The feathering pump motor becomes inoperative and the propeller de-icer bus again becomes energized.

Reversing Operation

Propeller reversing is initiated by moving the throttle into the reverse range. In order to move the throttle into the reverse range, the weight of the aircraft must be placed on the landing gear. This actuates a landing gear (safety) switch which energizes a throttle lock solenoid and removes the throttle detent to allow the throttle to be moved into the reverse range.

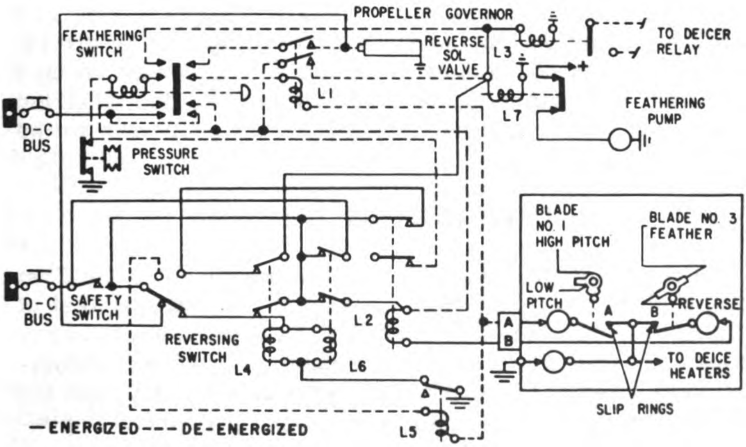


Figure 12-9.—Propeller reversing schematic diagram.

Figure 12-9 is the schematic diagram of propeller reversing system. As each throttle lever is moved aft of the idle position, the safety and reversing switches are

closed. This energizes the solenoid valve in the propeller governor, the feathering pump control relay $L2$, the feathering pump power relay $L7$, and relay $L3$ in the propeller de-icer circuit. The ground for the circuit through the relay coil of relay $L2$ is completed at the blade switch on the No. 3 blade. This circuit is broken 5 degrees prior to reaching full reverse position, interrupting the current through the feathering pump control relay $L2$, thus deenergizing $L7$ and $L3$. Relays $L4$ and $L6$ and the solenoid valve in the propeller governor remain energized as long as the throttle lever is in the reverse range.

Unreversing Operation

When the throttle lever is moved from the reverse range forward to idle, the reversing switch returns to its normal position. This completes a circuit through the feathering pump control relay $L2$, power relay $L7$, propeller de-icer relay $L3$, and interrupts the circuit to the solenoid in the propeller governor (fig. 12-10). The feathering pump then supplies oil to return the propeller blades to their normal position. When the blades reach a position a few degrees above the low-blade angle setting of the propeller, the blade switch completes a circuit through relay $L5$, deenergizing the entire circuit (relays $L2$, $L4$ and $L6$), stopping the auxiliary pump by deenergizing relay $L7$, and returning control of the propeller to the propeller governor.

PREFLIGHT INSPECTION

This inspection must be performed prior to the first flight of each day and is primarily an operational test of the equipment. It is assumed that the careful physical examination required by daily inspection has been accomplished after the last flight of the preceding day, and the propeller control system is operating properly. A preflight inspection consists of the following tests.

Govern Action Test

It is recommended that the synchronizer switch be placed in the manual position during all ground checks

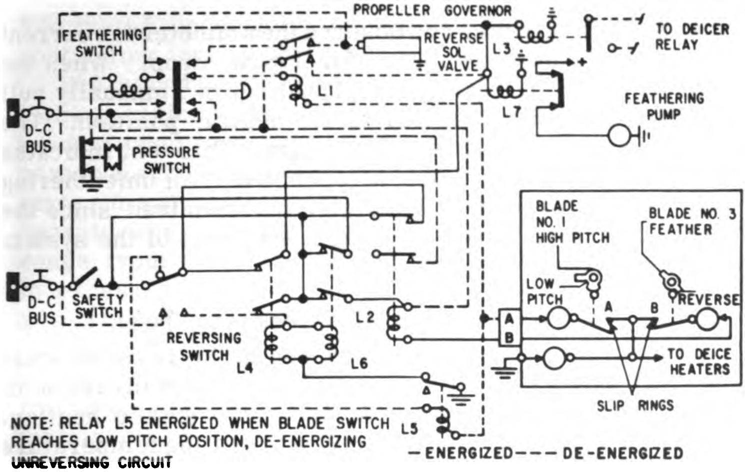


Figure 12-10.—Propeller unreversing schematic diagram.

other than when checking synchronizer operation. This prevents unnecessary running of the differential motors.

Upon completion of the engine warmup period, move the pitch control governing lever through its complete range from maximum to minimum r.p.m. several times. Return each propeller to its normal position by means of its individual toggle switch. Due to propeller pitch change, the engine r.p.m. should change in accordance with the throttle setting. This change in r.p.m. is indicated on the engine tachometer indicator.

This test serves to expel any air which may be trapped in the propeller system; and also it will enable you to detect improper operation of the propeller, the control system, or the engine.

Feathering and Unfeathering Test

The following method of testing the feathering operation with the engine running has two important advantages not attainable when carried out with the engine not running. They are: (1) the main control pump aids the auxiliary pump in supplying the necessary oil pressure; and (2) the feathering test more closely approaches the conditions under which the propeller would be feathered in flight.

With the r.p.m. control switch in the maximum r.p.m. position and the engine operating at 1,500 r.p.m., depress

the feathering switch and observe the ammeter for current drawn and the tachometer for r.p.m. drop. When the engine speed has dropped to 1,000 r.p.m., manually pull out the pushbutton switch to its neutral position. The engine should return to 1,500 r.p.m. This test indicates that the feathering pump is operative. An unfeathering test on the ground is generally not required since the feathering test shows that the main parts of the system are operative.

Reversing and Unreversing Test

The propeller should not be run in the reverse position for extended periods, since the reverse direction of propeller airflow will cause excessive engine heating. Maintain a careful check on engine operating temperature during all reverse pitch operations. Before starting the test for reversing operations, be certain that the aircraft is secured from moving either forward or backward. On aircraft with tricycle landing gear, operation in the reverse position may cause the tail to drop and preventive measures should be taken.

Place the throttle lever in the idle position and the r.p.m. control switch in the maximum r.p.m. position. This places the propeller in the low pitch position. Pull the throttle lever through the detent into the reverse portion of the quadrant. The decrease-pitch solenoid is then energized by a throttle-actuated microswitch. This causes the propeller to operate beyond the normal low pitch limit into the reverse pitch position. A slight increase in r.p.m. is normal and should be expected. The amount of reverse thrust may be increased by moving the throttle lever further to the rear and decreased by moving it forward toward the detent. To unreverse the propeller, advance the throttle lever past the detent to its original position. This unreverses the propeller, and the blades will rotate until they assume an angle of 5 to 12 degrees above the low pitch blade angle setting.

TURBOPROPELLER CONTROL

The turbopropeller has been designed for use on gas-turbine engines. This particular type propeller has not, as yet, been used extensively. However, the increasing usage of turbine engines that utilize propellers requires

that the AE understand the methods and systems used for controlling turbopropellers.

The aerodynamic actions of propellers used on gas-turbine engines are similar to the actions of propellers used on reciprocating engines. However, due to the comparatively higher power obtained from gas-turbine engines, the propellers on these engines must be able to operate over a wide range of aircraft speeds. These range from a very low speed up to and including speeds in excess of Mach 1. (Mach 1 = 763 m.p.h. at sea level at a temperature of 59° F.)

The turbine engines presently in use on naval aircraft are of the twin-turbine type. Each engine drives a contra-rotating, six-blade propeller. This propeller consists mainly of two three-bladed propellers. These are connected in such manner that they rotate in opposite directions and at equal speeds at all times. The rear three-blade propeller element is mounted on a large reduction gear (propeller) shaft and rotates counterclockwise. The front three-blade propeller element is mounted on a small reduction gear (propeller) shaft and rotates clockwise. Each of the three-blade propeller elements has its own separate, self-contained hydraulic control system.

These systems provide pitch control, automatic constant-speed governing, full feathering, unfeathering, and reverse pitch operation.

The block diagram in figure 12-11 shows the relationships between the fundamental components of the electronic governor and its related propeller and turbine components.

Each turbine has an a-c generator connected to its accessory drive pad, which supplies an a-c voltage to the electronic governor. The a-c generator output voltage represents the turbine speed in r.p.m. That is, the magnitude and frequency is proportional to turbine r.p.m.

The electronic governor utilizes a rectifier circuit to transform this intelligence from the a-c generator into a d-c potential. This d-c potential is proportional to the rate-of-change of the turbine's r.p.m. The output potential of the rectifier circuit has one polarity for accelerating conditions and the opposite polarity for decelerating conditions. When the turbine speed is constant, there is zero potential.

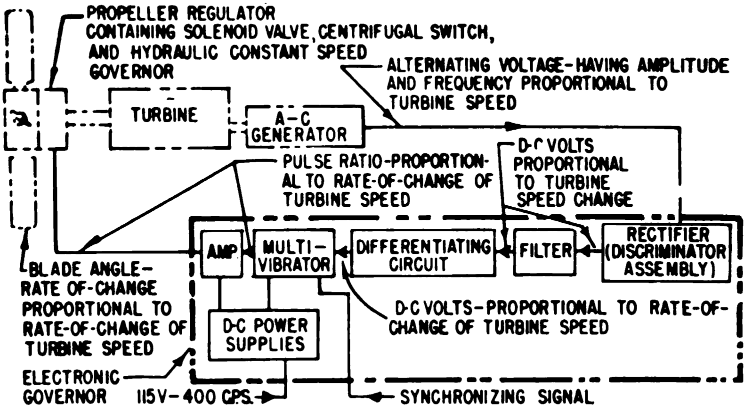


Figure 12-11.—Block diagram of governing system.

When the power plant is in a stabilized condition, the multivibrator assembly in the electronic governor produces two series of voltage pulses at a frequency of approximately 20 cycles per second. These two series of voltage pulses alternately energize coils on opposite ends of a solenoid valve in the propeller hydraulic system. This results in a net blade angle change of zero degrees.

During acceleration or deceleration, the potential difference from the speed sensitive circuit is fed into the multivibrator circuit and produces a voltage unbalance. This affects the pulse duration so that the voltage dwell is longer on one side of the solenoid valve than on the other, resulting in a net increase or decrease of propeller blade angle.

Synchronizing the r.p.m. of two or more different propeller assemblies is achieved through the use of a separately housed electronic synchronizer. This unit selects one engine as a master. When a difference of speed exists between the master and slaved engines, the slaved engines receive a controlling current flow to a motor-driven potentiometer. This potentiometer controls a biasing voltage which is fed into the pulsing (multivibrator) circuit in the electronic governors of those engines which are out of synchronization. This in turn biases the voltage pulses to the appropriate solenoid valves in the propellers. As

a result, the r.p.m. of all slaved propellers is made to synchronize with the master engine.

Since turbopropellers are not presently being used extensively on naval aircraft, information concerning their control is very limited. Should you be required to maintain such control systems, you should consult the handbooks for the particular system since these books contain detailed information concerning operation and maintenance.

TROUBLESHOOTING HINTS

If trouble occurs in the electrical controls of the propeller system, the first step of troubleshooting is to determine which part of the system is inoperative. This can be determined from the preflight check. The next step is to refer to the electrical schematic, found in the *Handbook of Maintenance Instructions* for the aircraft, and analyze the trouble.

QUIZ

1. The feathering pump is controlled by the
    a. number 3 blade switch
    b. feathering switch
    c. relay *L*3 (fig. 12-7)
    d. toggle switch

2. Failure of the master engine will cause the slave engine to
    a. decrease its r.p.m., but not more than 3 percent
    b. adjust to the r.p.m. of the master
    c. increase its r.p.m.
    d. remain constant

3. The synchronizer control can be deenergized by the use of the
    a. master lever control
    b. override relays
    c. synchronizer toggle switch
    d. differential motors

4. When operating in master lever control, this system controls
   a. separate speed adjustment of each propeller governor
   b. limited range synchronizer
   c. speed adjustments of all engines
   d. positive positioning against high r.p.m. stops only
5. The governor head consists of a permanent magnet rotor with a
   a. series winding
   b. shunt winding
   c. three-phase winding
   d. single-phase winding
6. When the governor lowers the rack, the compression in the speeder spring is increased and the engine r.p.m.
   a. increases
   b. decreases
   c. remains constant
   d. reaches minimum range
7. The master lever controls the
   a. master engine only
   b. slave engine only
   c. r.p.m. of both engines simultaneously
   d. r.p.m. of both engines separately
8. During takeoff both governors are locked in the positive high r.p.m. stops by the
   a. master lever
   b. synchronizer control circuit
   c. toggle switch
   d. three takeoff relays
9. The pitch indicator light indicates
   a. failure of the pitch circuit
   b. high r.p.m.
   c. low r.p.m.
   d. high and low r.p.m.
10. Termination of feather is determined by the
   a. feathering switch
   b. blade switch
   c. solenoid switch
   d. action of a relay
11. The feathering pump motor is a
   a. shunt-wound, d-c, constant-speed type
   b. series-wound, d-c, constant-speed type
   c. series-wound, intermittent-duty type
   d. three-phase, 27-volt, a-c type

12. The feathering switch hold circuit is deenergized by
    a. a relay
    b. the number 3 blade switch
    c. the number 1 blade switch
    d. the feathering switch button
13. The methods of controlling the governor head are
    a. automatic, synchronizer, and master level control
    b. manual, synchronizer, and master lever control
    c. manual, automatic, and master lever control
    d. manual, automatic, and synchronizer control
14. The synchronizer control senses difference of engine r.p.m. by utilizing
    a. 27 volts from the d-c bus
    b. the toggle switch
    c. the aircraft's tachometer generators
    d. changing d-c polarity
15. The r.p.m. reference for the synchronizer is obtained from the
    a. master engine
    b. differential motor
    c. slave engine
    d. synchronizer limiter

CHAPTER 13

D-C CONTROL, PROTECTIVE, AND WARNING DEVICES

Modern naval aircraft are equipped with many advanced electrical and electronic control, protective, and warning devices. The flight characteristics of aircraft are such that these devices must be more reliable than had been required in the past. The development of these more complex devices has increased the demands on maintenance personnel. Because of this, the knowledge and skill that you must possess has increased.

A protective device may be defined as "a device which is operated by a variation in its electrical or physical condition to effect the operation of other devices in an electrical circuit." Its principal function is to protect service from interruption or to prevent or limit damage to apparatus.

Protective relays, circuit breakers, fuses, and current limiters are examples of protective devices.

A control device may be defined as "a device, or group of devices, which serves to govern in some predetermined manner the electric power delivered to an apparatus to which it is connected." Control relays and switches are examples of control devices.

The determining factor as to whether a device should be classified as protective or control is the particular job that it is performing in a particular circuit. The same relay may be used for two different purposes in the same circuit. For example, in the auxiliary power circuit of a multiengine aircraft, it is used as a power relay

(control device) to start the auxiliary power unit. After the APU is started, the relay is used as a reverse current cutout (protective device).

There are many different d-c system control and protective devices. Some of these, such as switches, relays, voltage regulators, fuses, and circuit breakers, are explained in the Navy Training Courses, *Basic Electricity*, NavPers 10086, and *AE 3 & 2*, NavPers 10348. Those that are not included in these courses will be explained in this chapter.

CONTROL AND PROTECTIVE DEVICES

Relays

Relays are used as control and protective devices more than any other type unit. All relays have a certain classification. This classification may be determined from the letters and numbers that are printed on the relay's case. The type designation of a typical relay is as follows:

RY	1437	A	1
Component	Basic-type Indicator	Class	Enclosure

COMPONENT.—RY stands for armature relays. Most of the relays that you will work with are of this type.

BASIC-TYPE INDICATOR.—This indicator identifies the basic application for which a relay has been designed. A specific number within the ranges specified in table 13-1, for each basic application, is assigned to each relay.

Definitions of the basic application (table 13-1) of relays will be given since the Aviation Electrician will be better able to perform his work if he knows the design characteristics of the relay.

GENERAL PURPOSE.—A general purpose relay is one that operates upon the application of the operating voltage to the coil. It has no special features.

Table 13-1.—Basic-type indicator.

Symbol	Basic application
1,000 to 1,999, inclusive	General purpose.
2,000 to 2,999, inclusive	Marginal.
3,000 to 3,999, inclusive	Differential.
4,000 to 4,999, inclusive	Time delay.
5,000 to 5,999, inclusive	Latch-in.
6,000 to 6,999, inclusive	Ratchet.
7,000 to 7,999, inclusive	Selector.
8,000 to 8,999, inclusive	High speed.
9,000 to 9,999, inclusive	Sensitive.
10,000 to 10,999, inclusive	Polarized.
11,000 to 11,999, inclusive	Interlock.
12,000 to 12,999, inclusive	Special purpose.

MARGINAL.—A marginal relay is one which responds to make or break when the coil voltage or current reaches a predetermined value.

DIFFERENTIAL.—A differential relay is a multiple winding relay which operates when the current or voltage difference between the windings reaches a predetermined value.

TIME DELAY.—A time delay relay is one in which a delayed action is purposely introduced.

LATCH-IN.—A latch-in relay is one which is designed to lock the contacts in the deenergized position until the relay is either manually or electrically reset.

RATCHET.—A ratchet relay is one which operates in cycles in accordance with a successive or predetermined arrangement of impulses.

SELECTOR.—A selector relay is one which permits the selection of one or more circuits from a number of circuits.

HIGH SPEED.—A high speed relay is one which operates within 5 milliseconds.

SENSITIVE.—A sensitive relay is one which is designed to operate with a current flow of 100 milliwatts or less.

POLARIZED.—A polarized relay is one which is responsive to the direction of current flow.

INTERLOCK.—An interlock relay is one having two coils with their armatures and associated contacts arranged so that if one of the armatures is actuated, it

prevents the other armature from being actuated until the first armature returns to its normal position.

SPECIAL PURPOSE.—A special purpose relay is one designed for a specific purpose or application. Relays not covered in one of the basic applications just defined will come under the heading of special purpose.

CLASS.—The class is identified by a single letter. Table 13-2 shows the class symbols. These are based on the ambient temperature range for continuous operation, as shown in the table.

ENCLOSURE.—The enclosure is identified by a single number. Table 13-3 shows these symbols and the type enclosure designated by each.

Additional identifying information is contained on the relay case. This is as follows: (1) rated voltage or coil current, when applicable, (2) operating frequency, when applicable, (3) d-c coil resistance, (4) contact rating, (5) circuit diagram on case (applicable to sealed and enclosed relays only), and (6) manufacturer's name or symbol and manufacturer's designation.

Detailed information about a certain type of relay may be found in applicable military specifications.

A listing of current military specifications and standards is published in NA 00-25-544.

The contactor relays (power relays) are the workhorses of the aircraft's electrical system. These relays utilize coil currents of a fraction of an ampere up to several amperes. They are used to control power circuits carrying 600 amperes at 28 volts d.c. or 100

Table 13-2.—Temperature class.

Symbol	Temperature range
A	-55° C. to 85° C.
B	-65° C. to 125° C.
C	-65° C. to 200° C.

Table 13-3.—Enclosure.

Symbol	Type of enclosure
1	Open.
2	Enclosed (but not sealed).
3	Sealed.

amperes at 115/200 volts, 3-phase, 400-cycle, a.c. In addition to their high current ratings, these relays must also be capable of handling motor loads whose inrush current is six times the rated load. They must also be able to rupture ten times their rated loads for a limited number of operations.

The demands of modern aircraft have required that hermetically sealed relays be developed. A true hermetic seal is generally considered one that is metal to metal or glass to metal. Plastic or plastic rubber-type gasketed seals are generally not considered true hermetic seals.

Figure 13-1 shows a typical hermetically sealed contactor relay.

Some knowledge of the basic design fundamentals of relay construction is of value to operating personnel in understanding the operation and application of relays. In general, a relay is divided into three basic parts:

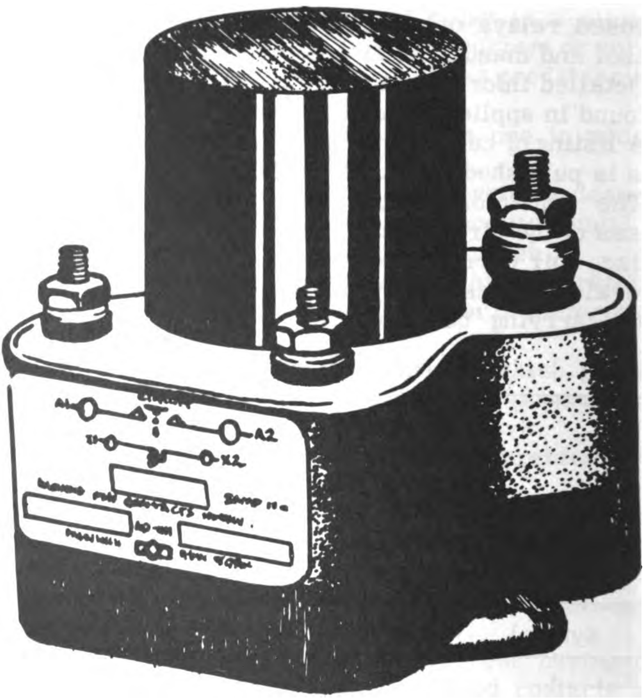


Figure 13-1.—A typical hermetically sealed contactor relay.

the magnet and associated coil, the contacts, and the mounting.

These components are used in a wide variety of forms. The configuration for aircraft control relays and power relays has been fairly well standardized. A manual switch, limit switch, or other small control device starts and stops the flow of current to the magnet coil.

The flow of electric current through the coil creates a strong magnetic field around and within the coil. This magnetic field is utilized to operate a movable clapper or plunger. The contacts which control the large current are fastened mechanically to this clapper or plunger, so that they make contact with nonmovable contacts to complete the circuit. Figure 13-2 shows a cutaway view of a 400-ampere, single-pole, single-throw contactor relay of the solenoid type.

Although representing a relatively small part of the total weight, the contacts are really the heart of both control and power relays. This is especially true of the power relays. The contacts must be made of a material that does not collect a current resisting film during arcing. A high voltage such as 115 or 200 will generally break through these films, but for 28-volt d-c applications a contact material must be used which will maintain a low contact resistance and not form high resistance oxides. To test the condition of contacts or relays, measure the voltage drop across the contacts at rated load. The average voltage drop of several readings should not exceed 0.1 volt.

The size of the contacts and the material from which they are made are determined in large part by the requirements of the military specifications and by the abilities of the designer.

It is possible, however, for contact failure to occur for one of several reasons. Usually this is due to usage beyond the requirements as set forth in the specification or to misapplication or misuse of the device.

Contacts may ultimately wear away if a sliding action is incorporated in the relay's design. Contact material may also be lost during arcing and can ultimately result in failure of the device. The latter condition occurs primarily in d-c circuits and can be detected by the excessive pitting of one contact and the building up of a

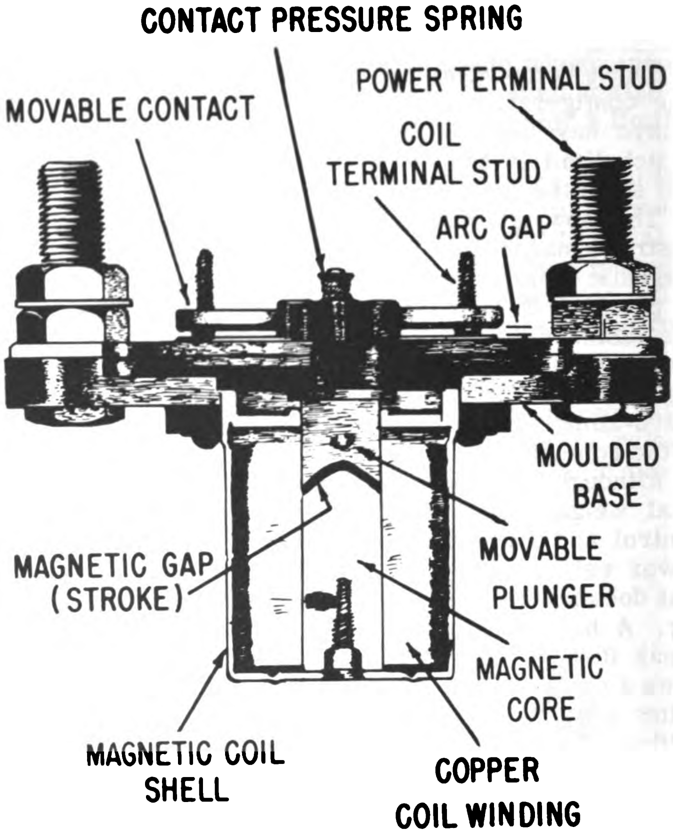


Figure 13-2.—Cutaway view of a 400-ampere, single-pole, single-throw contactor relay.

mound on its mating contact. Under these conditions, the life of the relay can be greatly extended by periodic reversals of the leads to power terminals. Care should be taken to see that this is not done with polarized or polarity sensitive relays, such as reverse current relays.

Most of the power relays used in aircraft use a silver alloy contact. These contacts usually contain oxides which reduce the tendency to weld.

The contacts of smaller ampere rating contactor relays are usually secured to the contact carrier by riveting or spot welding. The larger ampere rating

contactors are secured to the contact carrier by silver brazing.

Contact Support Plate

Closely allied in importance to the contact is the contact carrier or support plate.

The carrier material is selected for thermal and current carrying ability and mechanical strength. Copper, brass, and occasionally aluminum are the materials most commonly used. On the larger power relays the power terminal studs are usually of brass, copper, or copper alloy since strength and current carrying ability are required.

Coil and Magnet

Another major part of a relay is the magnet. The magnet is the device which converts the small amount of electrical energy in the coil into mechanical energy to bring the contacts together, which, in turn, controls a larger amount of electrical energy. Magnets are constructed in a variety of forms and shapes. However, aircraft relay magnets have been standardized into relatively few common types.

In the larger power relays (25 amperes up) where double-break contacts are used for increased current rupturing ability, the solenoid-type magnet shown in figure 13-2 is most frequently used. The high efficiency of this type of magnet counteracts the fact that it is not a "balanced-type" construction. It relies on the proper design of the return and contact springs for its resistance to shock and vibration, and has the advantage of being very simple mechanically. These devices seldom, if ever, fail mechanically when they are properly installed.

POLARIZED RELAY.—A polarized relay is a relay in which the movement of the armature depends upon the direction of the current in the circuit controlling the armature. The polarity effect is usually obtained by a permanent magnet acting on the armature. Figure 13-3 illustrates a simplified polarized relay.

The current which controls the pivoted armature *A* goes through coil *N*, whose magnetic force also acts on

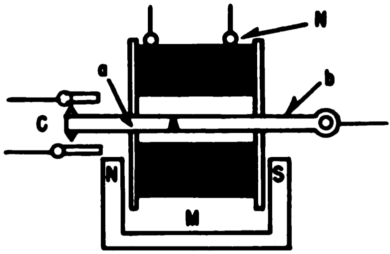


Figure 13-3.—Polarized relay (simplified).

the armature. When the direction of the current in the coil is such that it makes end *a* of the armature an N pole and end *b* an *S* pole, the armature will be repelled by the N and S poles of the permanent magnet *M*, and the armature *A* will move upward to close the upper contacts at *C*. When the current in coil *N* is reversed, and *a* becomes an S pole and end *b* an *N* pole. The armature will then be attracted downward to the two poles of the permanent magnet and the lower contacts at *C* will close. Hence, the operation of the relay depends on the direction of the control current. Such relays are used to prevent generators from being connected to the d-c bus in reverse polarity. An example of this is the Hartman reverse current relay, which was discussed in *AE 3 & 2,* NavPers 10348. The polarized relay is also used in many different control circuits.

POLARIZED DIFFERENTIAL RELAY.—This type relay has a multiple winding (usually two). The relay operates when the current or voltage difference between the windings reaches a predetermined value. In one type of polarized differential relay, the core of the relay has two windings. One of these windings has many turns of fine wire, while the other has a few turns of large wire. The two windings are wound on the core of the relay in opposite directions. The relay contacts are polarized, one contact being a north pole, the other a south pole. These polarized contacts are spring loaded open when the relay coils are deenergized. Figure 13-4 illustrates a simplified polarized differential relay.

Coil *B* of the relay core determines when contacts *C* will close. There are two factors that determine this;

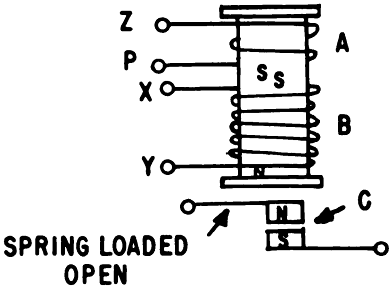


Figure 13-4.—Polarized differential relay (simplified).

the first being the direction of current flow through the coil. If current flows in the direction of *Y* to *X*, a magnetic polarity develops and causes the contacts *C* to remain open; had the current flow been from *X* to *Y*, a magnetic polarity would have developed to oppose the north pole contact.

The second factor is the magnetic strength, which is determined by the ampere turns of coil *B*. Since the contacts *C* are spring loaded open, it will be necessary to have a repelling magnetic strength strong enough to overcome the spring tension, allowing the N and S poles of the contacts *C* to come in contact with each other.

Once the contacts have closed, the magnetic strength of the two poles is strong enough to keep them closed. The only way the contacts may be opened is for a magnetic force to aid the spring. Coil *A* of the relay core, when energized with current flowing from *Z* to *P*, will develop a magnetic polarity to attract the N pole contact of contacts *C*, thus aiding the spring.

Once the contacts have opened, they will remain open because of the spring. This condition will remain until a current of the correct amount and polarity flows through coil *B*. Coil *B* usually operates on a differential voltage of about 0.5 volt d.c.; this produces a very small amount of current. Coil *A* usually operates on a large current flow, 15 amperes and up. The contacts of the polarized differential relay are very small in size and are designed to pass small amounts of current. These contacts usually control current to a contactor relay coil, which in turn

controls large current circuits. An example of this is the generator control circuits on most aircraft.

MARGINAL RELAY.—A marginal relay is one that responds to make or break when the coil voltage or current reaches a predetermined value. Examples of marginal relays are overvoltage relays, equalizer relays, and dropout relays.

Overvoltage relays provide overvoltage protection to systems and parts when overvoltage occurs. Overvoltage may be caused by failure of the voltage regulator or by short circuiting of the generator field to a voltage source.

The overvoltage relay is a sensitive, normally open relay. The relay coil is calibrated to trip at a safe predetermined value, usually at 30 volts, ± 0.5 volt, when protecting a 27.7-volt system. The contacts of the relay are in series with the generator's shunt field or in series with a field trip relay.

The overvoltage relay coil is in series with one and sometimes two resistors. If two resistors are used, one will be fixed and the other adjustable. Adjusting the variable resistor, will determine what value of overvoltage will cause enough current to flow through the relay coil to close its armature, thus opening the generator's field circuit.

EQUALIZER RELAYS.—These relays find frequent use in multigenerator aircraft. They detect any generator that "hogs" the load. The equalizer relay coil operates on a very small voltage, and it is of the polarized type. Figure 13-5 shows a simplified circuit diagram using the overvoltage relay and equalizer relay to obtain overvoltage protection.

Assuming that the number one generator in figure 13-5 is taking all the load, point *d* at the number one generator will be more negative than point *d* of the number two generator. Since current flows from negative to positive, there will be a current flow from the number one generator to the number two as shown by the arrows.

Due to the direction of current flow through the equalizer relay coils, the two relays operate in opposition. As seen in figure 13-5, the number one generator equalizer relay will open its contacts, allowing the number one generator's high voltage to be applied to the overvoltage relay. During this time the number two generator's

equalizer relay contacts remain closed, shunting the bus voltage around its overvoltage relay. Using this relay arrangement allows the overvoltage relays to disconnect the offending generator from the system if its voltage reaches an unsafe value.

There are many ways of providing overvoltage protection. However, no matter what method is used, the basic principle of operation is as illustrated by the simplified circuit shown in figure 13-5. When information about the system used in a particular aircraft is desired, consult the HMI for that aircraft. It should be noted that all systems are similar since they must conform to standard drawings as prescribed by BuAer.

A dropout relay is another form of marginal relay. Figure 13-6 shows a typical jet aircraft starter control circuit utilizing the dropout relay.

This particular relay employs three coils. Coil *A* is a contactor coil, coil *B* is a holding coil, and coil *C* is a current coil. The two sets of contacts are controlled by these three coils.

When the starter switch is positioned to start, coils *A* and *B* become energized, closing contacts *B* and *E*. This

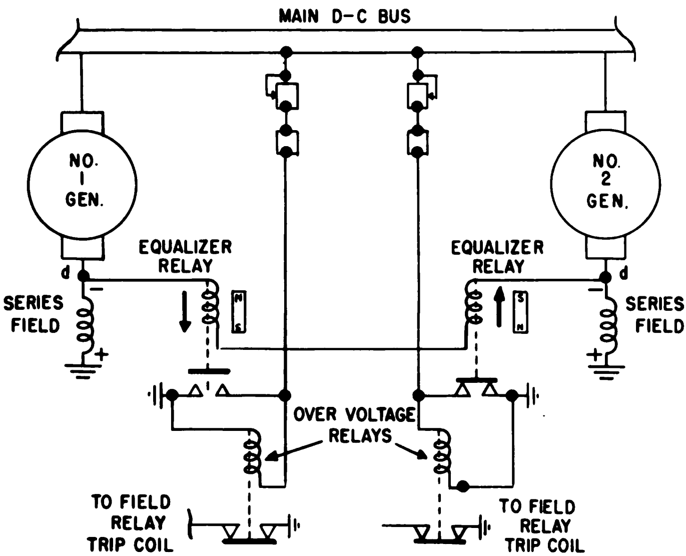


Figure 13-5.—Simplified overvoltage protection circuit.

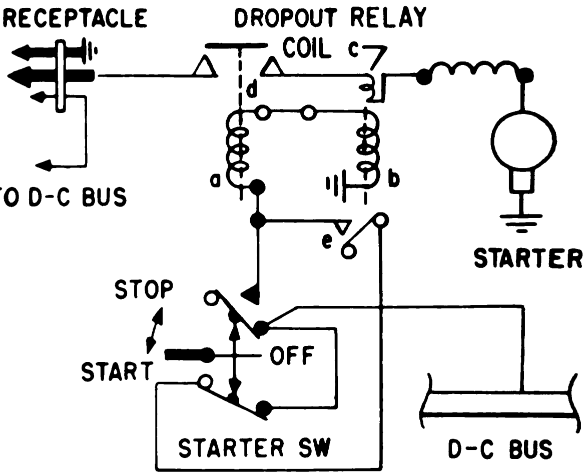


Figure 13-6.—Typical jet aircraft starter control circuit.

allows the starter to receive current. The current demand will be very large, usually 1,000 to 1,200 amperes. Due to the large current flow through coil *C*, it aids coil *B* in keeping contact *E* in the closed position. This position is maintained even though the pilot has allowed the starter switch to return to the OFF position.

As the starter turns the engine over, the current demand of the starter will become less. This allows the magnetic field of coil *C* to become weaker. When the engine r.p.m. reaches approximately 18 percent, the magnetic field of coil *C* will be weak enough to allow contacts *E* to open. This removes the current flow from coil *A* and coil *B*, thus allowing the contactor contacts to open, stopping the starter.

TIME DELAY RELAY.—This is a relay with delayed action purposely introduced. One common form of time delay relay uses a bimetallic element which bends as it is heated. The element is made by welding together two strips of different metals having different thermal expansion rates. A heater is mounted around or close to the element. The contacts are mounted on the element itself. As the heat causes the element to bend, because of the different thermal expansion rates, these contacts close to operate a relay. The delay time of the bimetallic

strips is usually from 1/2 to 1-1/2 minutes and is varied by using metals with different expansion rates or by increasing or decreasing the distance between the fixed and moving contacts. Figure 13-7 illustrates a thermal time delay relay.

Another common form of time delay relay utilizes a lag coil (slug). This is usually a large copper slug that is located at one end of the winding or a tubular sleeve that is located between the winding and the core.

The lag coil acts as a short circuited secondary for the relay coil. The counter magnetomotive force, due to the current induced in the coil by the changing coil current, delays the flux buildup or decay in the air gap and hence the closing or opening of the armature. A short slug near the armature end of the core has relatively more effect on the operating time and one at the heel end has more effect on the release time. Figure 13-8 illustrates a lag coil time delay relay.

The dashpot-type time delay relay is used in some time delay applications. A magnetic coil pulls a plunger through a dashpot which may be either oil or air filled. A small hole in the plunger allows the oil or air to pass

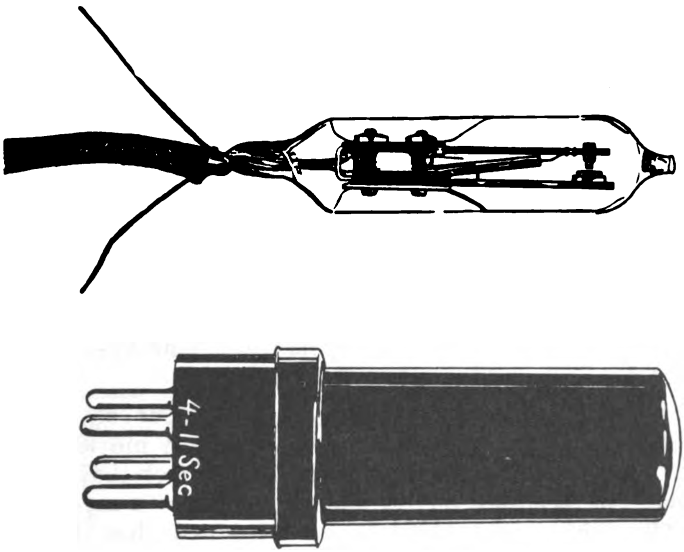


Figure 13-7.—Thermal time delay relay.

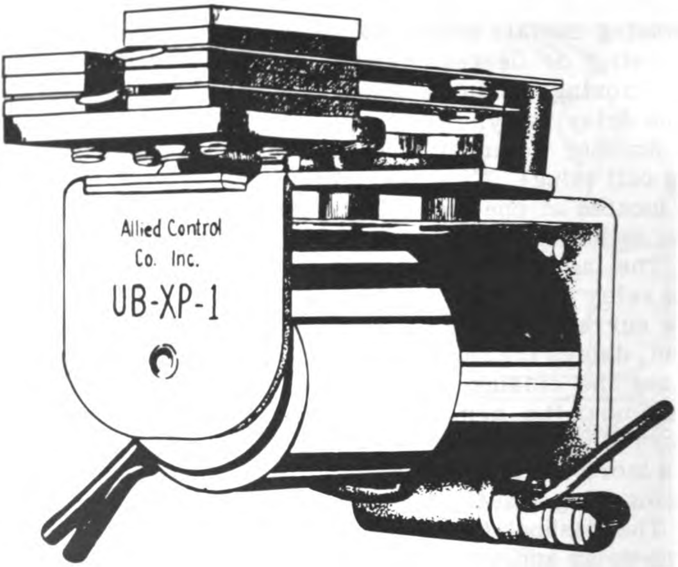


Figure 13-8.—Lag coil time delay relay.

through. The time delay can be varied by changing the size of the hole in the plunger.

LATCH-IN-RELAY.—This relay is designed to lock the contacts in the deenergized position until the relay is either manually or electrically reset. A good example of the latch-in relay is the field relay employed with the overvoltage control circuit that is used in many multi-generator aircraft. In this particular circuit, the field relay opens the generator field circuit when the field relay has been energized by the overvoltage relay.

The latch-type field relay has two windings. One is the trip coil, and the other the reset coil.

When the trip coil is energized with current, it acts on a spring-loaded armature. The relay's movable contacts are mounted on this armature. After the contacts open they are held in the open position by a mechanical latch. The mechanical latch is unlatched when the reset coil is energized, thus allowing the relay's contacts to close again. Figure 13-9 illustrates an electrically reset

latching relay. The latch-type relay will be further discussed later in this chapter.

Ground and Feeder Protector Relay

There is much need for circuit protection between the aircraft's generators and the main bus. Since the generators are capable of delivering high amperage, the danger of shorts and grounds must be guarded against to prevent fire or serious damage to the aircraft. The ground and feeder protector relay is used for this purpose. Figure 13-10 shows a typical circuit diagram of the ground and feeder protector relay.

The relay is connected in the d-c generator circuit to protect the circuit from any faults that might occur between the generator and the main d-c bus. Systems that use the ground and feeder protector relays will employ one such relay for each d-c generator. The ground and feeder protector relay has four coils, wound on a common core, which control a set of contacts. Coil 1, as illustrated in figure 13-10, is connected in series with the positive feeder lead of the generator; coils 2 and 3 are connected in parallel with each other and in series with coil 1. Coil 4 is connected in series with the negative feeder lead of the generator.

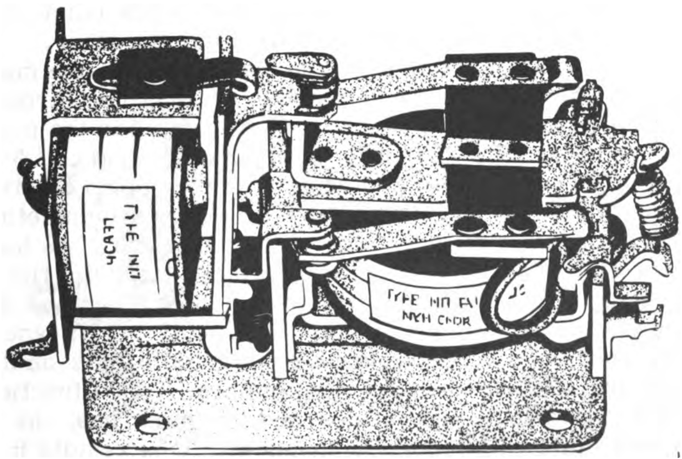


Figure 13-9.—Electrically reset latching relay.

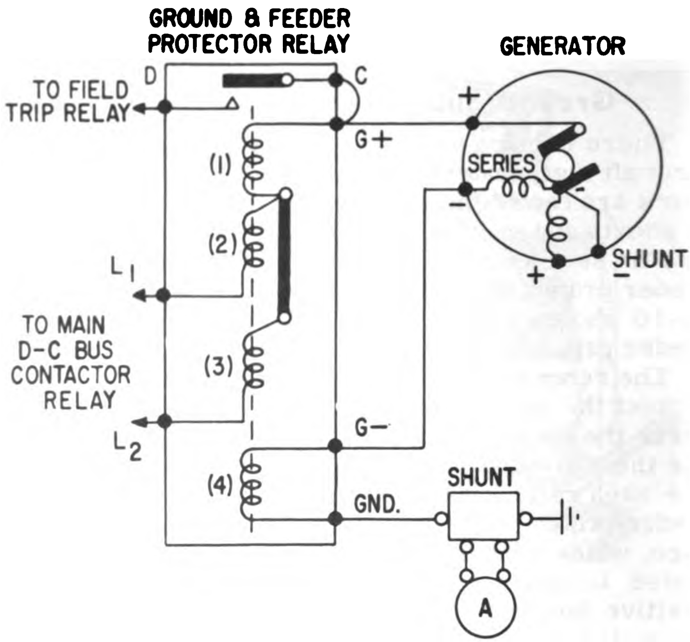


Figure 13-10.—Typical circuit diagram of the ground and feeder protector relay.

Coils 1 and 4 are wound in opposition to each other, and coils 2 and 3 are wound in opposition to each other.

When the generator is delivering current to the main d-c bus, the current flow from the generator is through coil 4 to ground, through the loads connected to the main bus, and from the main bus through coil 2 and coil 3 of the ground and feeder protector. At this point the two currents join and flow through coil 1, thus completing its circuit to the positive side of the generator. As long as the circuit is functioning properly, the magnetic fields set up by coil 1 and coil 4 will cancel each other and the magnetic fields set up by coil 2 and coil 3 will cancel each other. As a result, no magnetic field acts on the armature, and the contacts remain open. If a malfunction occurs between the generator and the main bus, one of the four coils will become unbalanced. This results in a magnetic field being produced. The field acts on the relay armature which, in turn, causes the relay's contacts to

close. When these contacts are closed, a trip relay is energized. This, in turn, opens the generator's shunt field circuit and removes the generator from the d-c bus. Figure 13-11 shows a ground and feeder protector relay.

Contactor and Feeder Protector Relay

A contactor and feeder protector relay works in conjunction with a ground and feeder protector relay. The

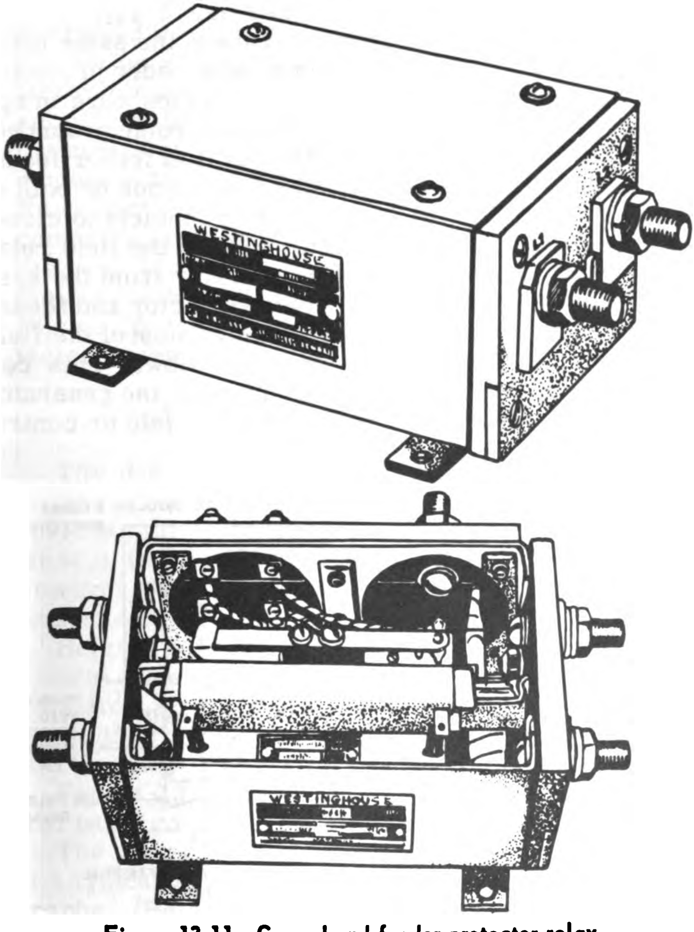


Figure 13-11.—Ground and feeder protector relay.

purpose of this relay is to connect and disconnect the generator to the d-c main bus. Also, it provides feeder protection between the ground and feeder protector relay and itself.

Normally, the ground and feeder protector relay is located as close to the generator as practical, and the contactor and feeder protector is located at the main d-c bus.

The contactor and feeder protector assembly consists of four relays within one case. (See fig. 13-12).

Coils 1 and 2 in this relay operate in the same manner as coils 2 and 3 in the ground and feeder protector relay; that is, they are wound on a common core in opposition. Should the feeder leads fail or become grounded, an unequal current will flow in the parallel feeder leads. This produces an unbalanced flux field in one or both of the protector relays, causing the relay contacts to close. When the relay in either protector closes, the field relay opens (trips), disconnecting the generator from the system. This differential relay, in the contactor and feeder protector, has a third coil through which most of the field current and control circuit currents flow. This coil serves to trip the field relay and remove the generator from the line when faults develop in the field or control circuit.

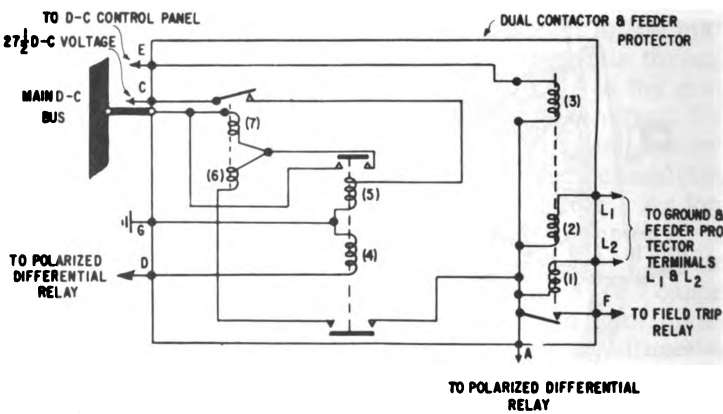


Figure 13-12.—Schematic diagram of the dual contactor and feeder protector relay.

In addition to the differential relay, the dual contactor and feeder protector contains dual contactor relays. The contacts of these relays are connected in series with the main bus to insure positive interruption of the generator current when a reverse current condition exists. Also, they serve to connect the generator to the main bus, provided current flow is in the normal direction. By connecting the two contactors in series, double protection is provided; should one fail to open, the other will continue to protect the circuit. This second contactor is energized through the parallel coil (coil 7) of the backup protection relay. The coil is shorted out when the contactor closes. However, the series coil of the backup relay (coil 6) is in series with the main line and keeps the contactor energized. If, on reverse current, the first contactor fails to open, the series coil (coil 6) will force its contacts open at about 100 amperes, dropping out the contactor, and thereby disconnecting the generator from the bus. If a heavy surge of reverse current flows from the bus, both contactors will open almost simultaneously. Figure 13-13 shows the dual contactor and feeder protector assembly.

D-C Generator Control Panel

The d-c control panel, as shown in figure 13-14, is an assembly that employs many control and protective devices, all of which are contained in the same case. Most of these have already been discussed individually. However, it is important to see how they are interconnected.

Referring to figure 13-14, the following parts of the control panel can be identified: (1) carbon pile voltage regulator, (2) male plug, (3) voltmeter pin jacks, (4) output voltage regulating rheostat, (5) manual reset button, and (6) control relays (enclosed).

Figure 13-15 shows a schematic diagram of the control panel connected in a d-c generating control system.

The operation and functions of the various elements of a typical system are discussed in the following paragraphs. (Refer to fig. 13-15.) To connect the generator to the aircraft bus, close the generator switch. If the generator voltage is 22 volts or more and of the correct

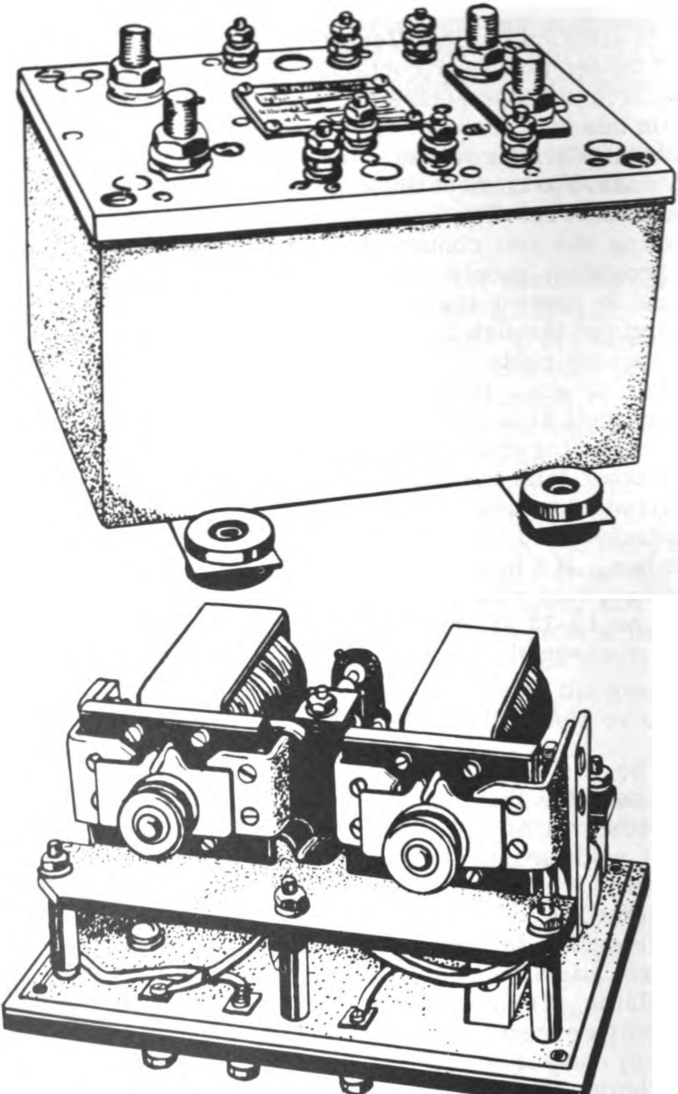


Figure 13-13.—Dual contactor and feeder protector assembly.

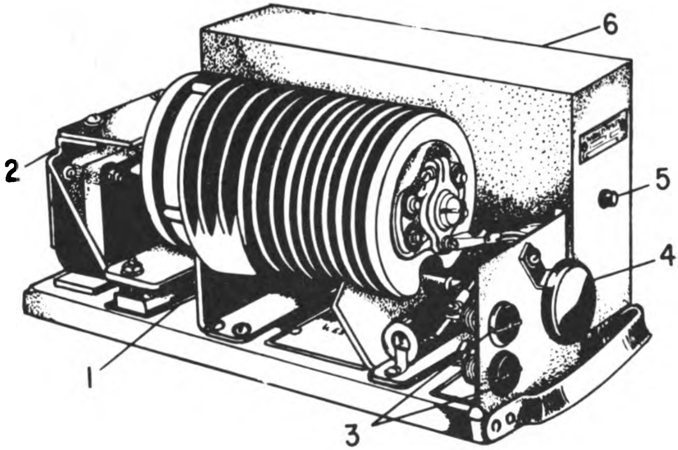


Figure 13-14.—Generator control panel, type AVP-109C.

polarity, the polarized voltage relay will be closed. Note that one side of the polarized voltage relay winding is connected to ground, while the other side is connected to terminal *E* of the dual contactor and a feeder protector.

The polarized voltage relay protects against reversed generator polarity by keeping a reversed generator off the bus. Closing of the polarized voltage relay contacts connects the voltage coil of the polarized differential relay between the generator's positive terminal and the bus. This coil then senses the difference in voltage between the generator and the bus. The polarized differential relay contacts will not close until the generated voltage is higher than the bus voltage by at least 0.5 volt. This is the proper voltage relationship for connecting a generator to a bus. When the polarized differential relay contacts close, the contactor coil and differential relay holding coil circuits are completed through the generator switch.

When the generator switch is closed, it also applies generator voltage to the equalizer disconnect relay coil and to terminal *C* of the dual contactor and feeder protector. The equalizer disconnect relay picks up at approximately 20 volts and connects the regulator equalizer coil to the equalizer bus. The first line contactor also closes, allowing a small current to flow from the

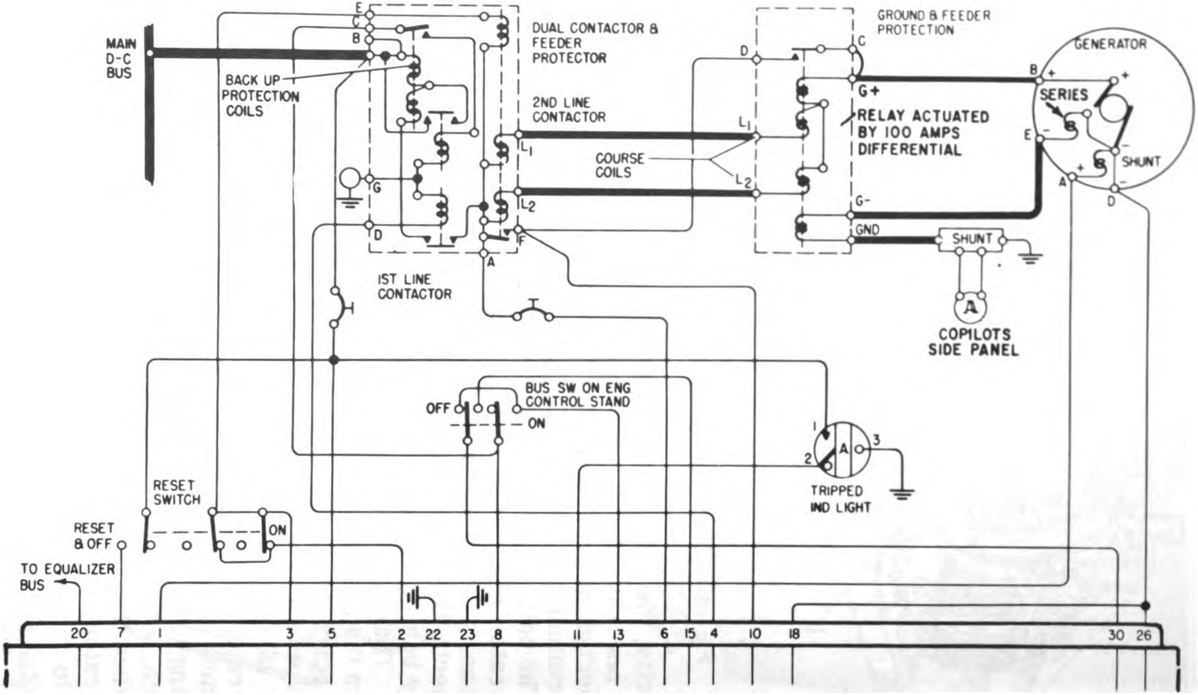


Figure 13-15.—D-C generating and control system, schematic diagram.

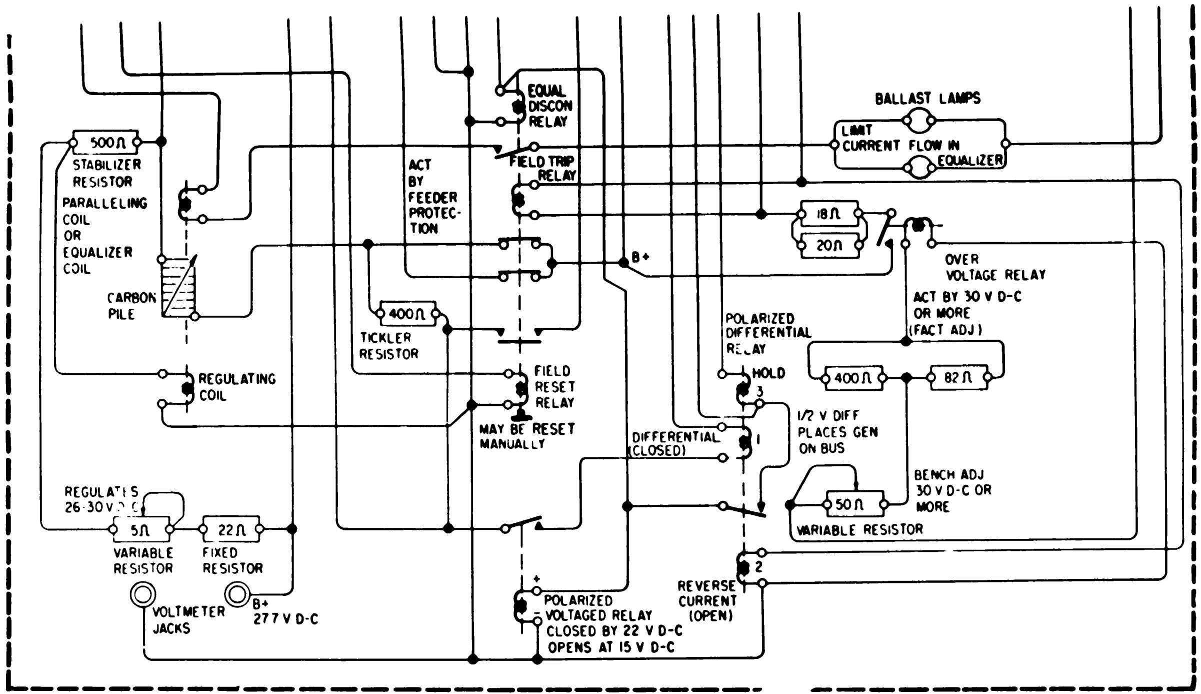


Figure 13-15.—D-C generating and control system, schematic diagram.—Continued

generator to the bus through the multiturn coil of the backup protection relay. This is sufficient to close the contacts, completing the circuit of the second contactor to the generator output, bringing the generator on the bus. The single-turn coil on the backup relay is then in series with the line from the generator to the bus and holds the contact closed after the contactor closes, shorting out the multiturn coil. When other generators, properly adjusted, are connected to the system in the same manner, they will operate in parallel. If the battery switch has been closed, the batteries will be in parallel with the generators.

The equalizing coils on the voltage regulators are used to maintain equal load division between the generators. The voltage needed to operate the equalizer circuit is obtained from the voltage drop in the series winding of the generator. If one generator tends to take more of the load than the others, the voltage drop on its series winding will be higher. This difference in series winding voltage drop is impressed upon the voltage regulator-equalizer-coil circuit. This causes the generated voltage of the generator taking excessive current to decrease, and raises the generated voltage of the other generators, thus equalizing the generator loads. When one generator speed is decreased to a point where its voltage cannot be maintained, the other generators or battery will try to drive it as a motor. The reversed current in the series winding causes a reversed voltage drop to be impressed on the reverse current indicator winding of the polarized differential relay. When the reverse current has increased to approximately 25 amperes, the polarized differential relay will open its contacts. This, in turn, opens the line contactor which disconnects the generator from the system. When the system is operating normally, the reverse current indication winding tends to hold the differential relay closed. The purpose of the holding winding on the differential relay is to make it possible to set the relay so its contact will always return to open position whenever the generator switch is opened or the field relay is tripped by a fault. This eliminates the possibility of connecting a reversed generator on the bus under any condition.

Use of the series winding method of paralleling produces a very strong equalizing action. The voltage drop

across the generator series winding at rated load is between 1.6 and 2.3 volts, depending upon the winding temperature. This temperature is affected by the cooling air head pressure and cooling air temperature, as well as the generator load. In the case of one generator being reduced to idling speed, this strong paralleling action would cause the system to be reduced to an objectionably low value. Ballast lamp resistors are used in the equalizer circuit to maintain a high system voltage under the conditions just mentioned. These resistors, or lamps, experience a resistance change as the current through them changes. Thus, at low currents they offer only a small resistance; at relatively high currents, the ballast resistors offer a high resistance which reduces the equalizer current. Thus, the ballast resistors allow good parallel operation of the remaining generators with a minimum bus voltage change with one or more generators running at a slightly lower speed. When a generator switch is opened and the generator shuts down, the equalizer disconnect relay will open the equalizer circuit of that generator, allowing the remaining generators to share the load.

In case of a generator or feeder fault, the field relay will be tripped. This opens the contactor circuit and the generator field circuit. Tripping the field relay also closes the trip indicator light circuit. After either a fault or overvoltage condition has tripped the field relay, it must be reset. This is the only time that the reset operation is required. This may be accomplished by moving the reset switch to RESET position, putting bus voltage on the reset coil, or by operating the manual reset button.

When excessive voltage occurs on one of the generators, the overvoltage relay of its control panel operates to remove this generator from the system. Excessive voltage may be caused by broken leads, shorted terminals, shorted leads, or any other external fault which causes the generator field current to be out of the control of the voltage regulator. The generator producing overvoltage raises the bus voltage, resulting in reverse current flowing through the other generators, which are being regulated at normal voltage. The reverse current causes the main contactors of the normal generators to open.

With the normal generators removed from the system, the offending generator voltage will rise still higher, resulting in operation of the overvoltage relay which, in turn, opens the field of the offending generator. The generators taken off the bus by reverse current will return to normal operation when the generator with high voltage has been removed. When a generator has been removed from the system due to overvoltage, it may be returned to the system by placing the reset switch in RESET position. If the generated voltage is still high, the overvoltage relay will again remove the generator from the system.

There are many similar d-c generator control systems used in the Navy, usually the different aircraft manufacturers select the method best fitted to their aircraft's airframe.

POWER AND NONINSTRUMENT WARNING DEVICES

In today's fighting aircraft, many different electrical, mechanical, and hydraulic systems must operate simultaneously. It is necessary to provide a visual indication of equipment trouble or alternate operation of equipment to the pilot and his crew members. Warning and indicator lights are used since they are small in size, light in weight, low in cost, and attract one's eyes at the instant they are energized. The brilliance of the warning and indicator lights is usually controlled by a rheostat. The operational condition of the light can usually be tested by a warning light test switch; in most circuits the light is a push-to-test type. These warning and indicator lights are installed in the following circuits: (1) d-c and a-c power circuits, (2) positioning circuits, (3) quantity and pressure circuits, and (4) overheat circuits.

Power Warning and Indicating Lights

Warning and indicating lights used in power circuits will give visual indication under the following conditions: (1) when the d-c generator fails to supply voltage to the main d-c bus, (2) when a power circuit becomes shorted or grounded, (3) when the armament bus has voltage

applied to it, and (4) when the inverter fails to supply an a-c voltage of the correct amount and frequency to an a-c bus. For an example of a warning light circuit, refer to figure 13-15 which shows a warning light used in the d-c generator power and control circuit.

Position Warning and Indicating Lights

Lights that are used in positioning circuits are important since they indicate either a safe or unsafe condition of a particular control or mechanism. The pilot relies upon these indications in determining the safe operation of the aircraft. Some of the circuits that utilize these lights are: (1) landing gear, (2) tailhook, (3) hatch, and (4) propeller pitch.

Figure 12-4 of chapter 12 illustrates an indicating light circuit. It indicates when the propellers have reached the high or low pitch stops.

Overheat Warning and Indicating Lights

These lights are used for warning and indicating when an overheating has occurred. For example, this may occur as a result of (1) the d-c generator overheating due to the lack of ventilating air, (2) an overloaded generator, (3) a bearing becoming overheated, or (4) a shorted or grounded generator field.

Figure 13-16 shows a schematic diagram of a generator overheat warning circuit.

The overtemperature switch is a thermoswitch that is embedded in the generator's yoke. This thermoswitch is designed to close its contacts when the temperature in the embedded area reaches a specified temperature. As the contacts close, a ground is completed to an overheat warning light. This light is located where the pilot or crew members can easily see it, and thereby detect the trouble before any serious damage occurs.

Fire detection systems have become mandatory equipment for practically every aircraft built since 1946. Warning lights are used to indicate when there is a fire aboard an aircraft. Figure 13-17 shows a jet engine fire detection sensing circuit.

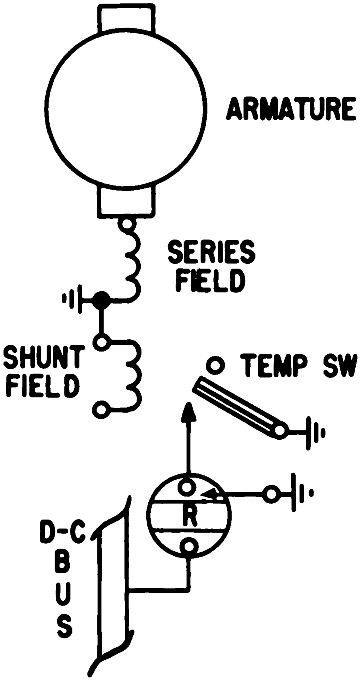


Figure 13-16.—Generator overheat warning schematic diagram.

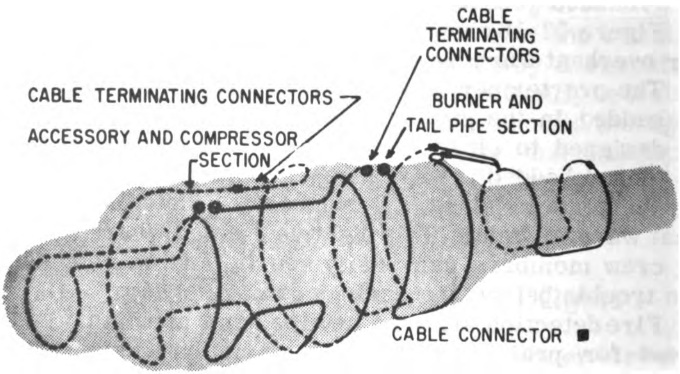


Figure 13-17.—Jet engine fire detection sensing circuit.

Figure 13-18 shows the schematic diagram of a typical fire detection system. This system utilizes a d-c bridge circuit that controls a relay. The relay coil becomes energized when the detector sensing cables are subjected

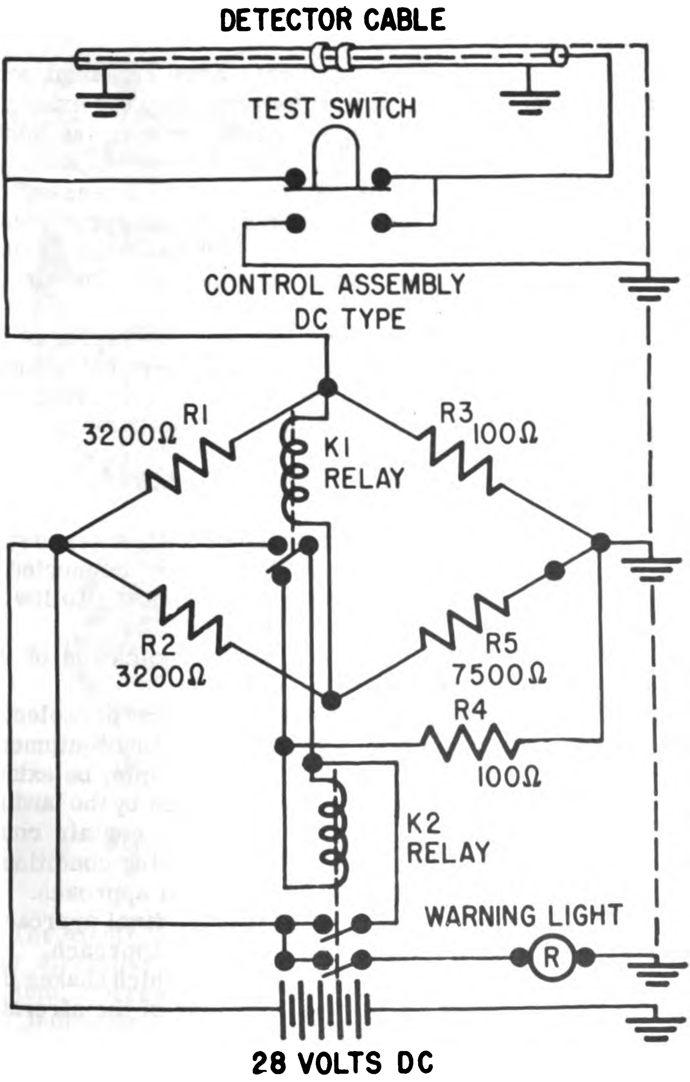


Figure 13-18.—Schematic diagram of a fire detection system.

to abnormal heating, due to a fire. This, in turn, allows d-c voltage to be applied to a warning light. All fire warning lights emit a red glow.

Quantity and Pressure Warning Lights

In many aircraft, warning lights have replaced some of the pressure and quantity instruments; for example, some fuel and oil pressure systems utilize warning lights. A pressure switch is installed in the fuel or oil line. As the pressure of the fluid decreases or increases, the pressure switch will make contact. This completes a ground to a warning light. These systems may be used to indicate when the pressure is either too low or too high.

Some fuel quantity systems use warning lights to indicate when the aircraft's fuel is low. The warning lights are operated by a float switch, located in the fuel cell, or a switch located in the fuel quantity indicator.

STALL WARNING SYSTEMS

The angle of attack system is essentially a servo system which, when installed in an aircraft and connected to the aircraft's electrical system, performs the following functions:

1. Provides the pilot with a visual indication of the angle of attack of the aircraft.
2. Actuates electrical switches at various preselected angles of attack to energize optional accessory equipment. Such accessory equipment might, for example, be external colored approach lights for observation by the landing signal officer of an aircraft carrier. A certain color light is used to indicate each of the following conditions:
   HIGH—angle of attack too high for final approach.
   MEDIUM—correct angle of attack for final approach.
   LOW—angle of attack too low for final approach.
3. Actuates a rudder shaker circuit, which shakes the rudder pedals prior to the stall attitude of the aircraft, thus warning the pilot.

The units of an angle of attack system are shown in figure 13-19. A typical angle of attack system installation is illustrated in figure 13-20.

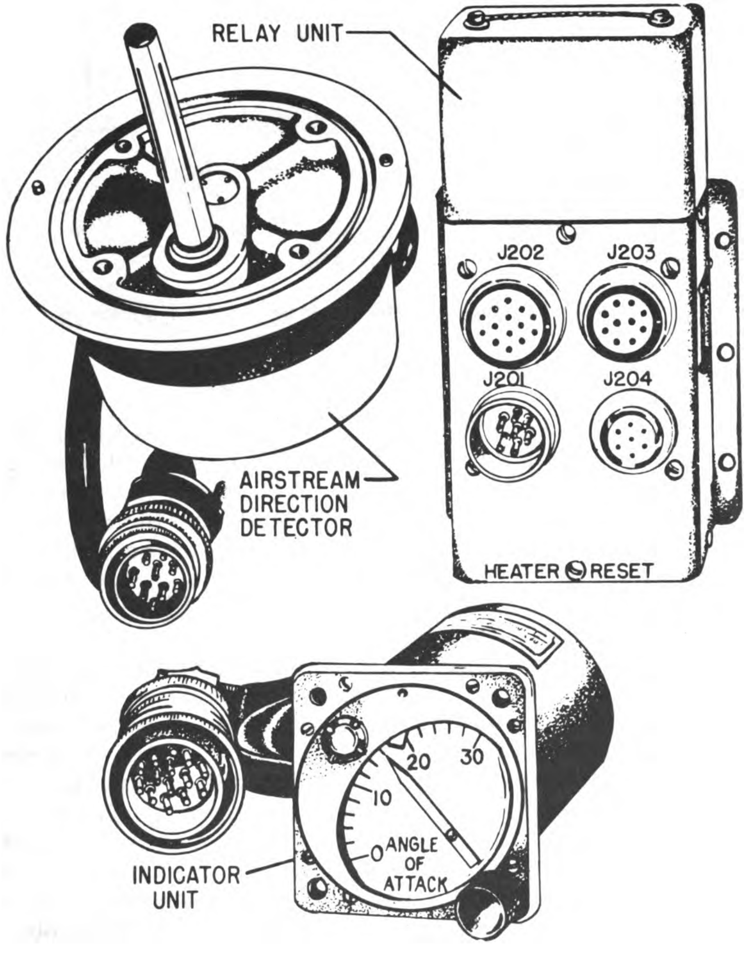


Figure 13-19.—Angle of attack system—units.

The airstream direction detector senses the local airflow direction and, by means of the electrical servo system, correspondingly positions a pointer on a dial in the indicator unit which is mounted on the instrument panel. The relay unit serves as an amplifier in the servo system and as a junction box for the interconnecting cabling.

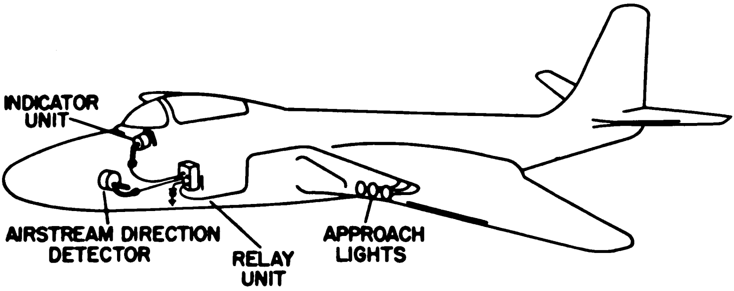


Figure 13-20.—Angle of attack system—typical installation.

Airstream Direction Detector

The airstream direction detector measures the direction of local airflow with an accuracy of 0.1 degree at indicated airspeeds in excess of 90 knots. The body of the unit is mounted within the fuselage and the cylindrical probe extends outward through the skin of the fuselage. Dowel pins in the circular mounting flange engage mating holes in the mounting plate, which is part of the airframe, to assure proper angular positioning.

The tubular probe is sealed at both ends and is divided into two parallel air passages by means of a full length separator. Two longitudinally parallel slots, one for each passage, are milled through the wall of the probe near its outward end and two corresponding orifices are drilled into the passages near the base of the probe. The main housing casting is cylindrical and encloses a balanced paddle which is pivoted on ball bearings. (See fig. 13-21.)

Outside the paddle chamber a crank arm on the end of a paddle shaft engages an arm, fixed to the base of the probe, to transmit paddle rotation to the probe. The arm fixed to the probe carries two wipers incorporated with two electrically independent toroidal potentiometer windings. These potentiometers provide an electrical signal dependent on probe position. Only one of these potentiometers is used for the angle of attack system; the other is used as a source of angle of attack information for other computing equipment in the aircraft. A thermostatically controlled de-icing heater is enclosed within the separator in the probe; and an additional thermostatically controlled internal heater eliminates condensation within the unit.

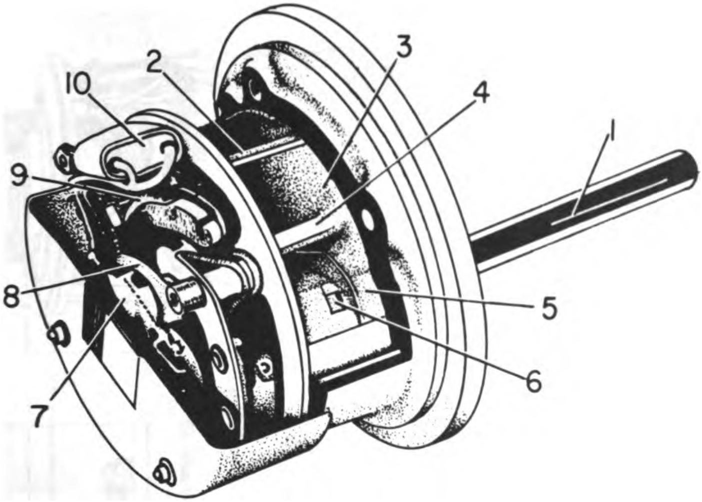


Figure 13-21.—Airstream direction detector, cutaway view.

1. Probe.
2. Paddle.
3. Paddle chamber.
4. Paddle shaft.
5. Air stator sector.
6. Filler assembly.
7. Crank arm.
8. Wiper arm.
9. Potentiometer winding.
10. Thermostat.

A cover for the probe is supplied with each airstream direction detector to protect the internal mechanism when the aircraft is stored in the open or when the aircraft is being washed down.

Relay Unit

The relay unit houses the various electrical components of the servo system and serves as a junction point for the system cabling. This unit contains a sensitive polarized relay, a power relay, two approach light relays, a radio interference filter, a 3-ampere manual reset thermal circuit breaker located in the probe heater circuit, and various resistors. These parts are shown schematically in figure 13-23.

Indicator Unit

The indicator unit is mounted on the instrument panel so that its dial and pointer are visible to the pilot. The

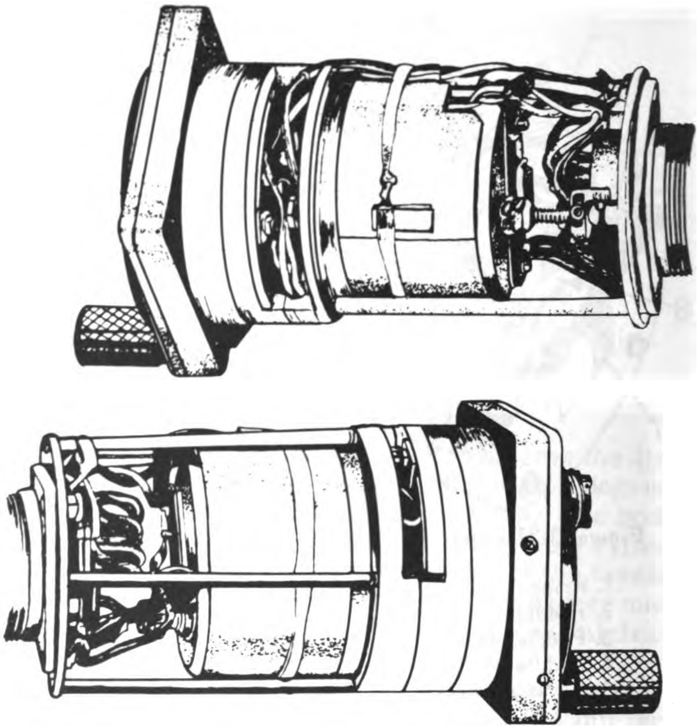


Figure 13-22.—Indicator unit.

dial is graduated from 0 to 30 in fifteen increments. A pointer sweeps from 0 to 30 as the probe of the airstream direction detector is rotated from one limit to the other. A movable reference index can be positioned along the outer edge of the scale by rotating a knob at the lower corner of the mounting flange.

The dial light is contained in a removable housing at the upper left of the dial. The dial is adjustable one-half scale division either way from center to compensate for airframe tolerances in the zero lift angle of attack in individual aircrafts of like type. At the center of the adjustment range, the zero graduation on the dial is aligned with an index mark on the bezel. The dial is clamped in position by two setscrews in the bezel. (See fig. 13-19 (indicator unit).)

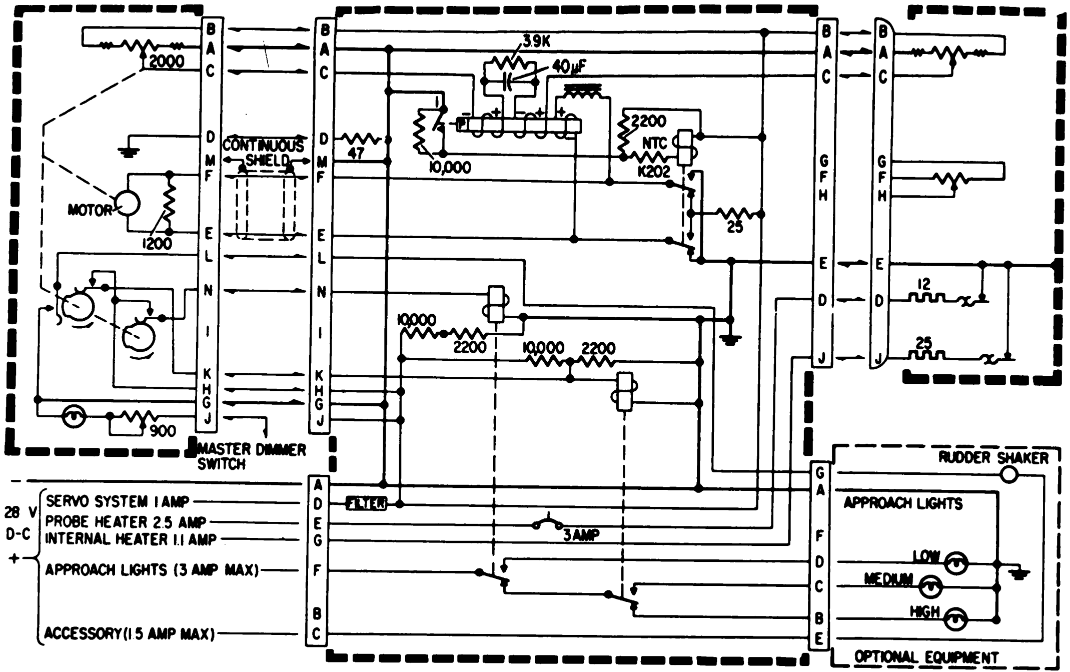


Figure 13-23.—Angle of attack system, electrical schematic diagram.

Near the rear of the unit, within the cylindrical cover, is a servo-motor with an integral reduction gearbox and a slip clutch. (See fig. 13-22).

Motor rotation is transmitted to a central shaft. Two cams are mounted on this shaft. The lobes of these two cams actuate three snap-action switches. Two of these switches are wired through the two relays in the relay unit. These relays control the approach lights. The third switch is wired direct to a rudder shaker circuit, if used.

Each switch is mounted on an arm pivoted about the cam shaft and secured with an adjusting screw to the body of the unit. Thus, each switch can be positioned angularly with respect to the actuating lobe of its associated cam to regulate the point of closure of the switch contacts.

The camshaft also carries a potentiometer wiper arm. This is the receiver potentiometer in the servo system.

Rearward of the servomotor is the dial light intensity control. It consists of a resistance winding with a movable slider. The slider is adjusted by means of a recessed slotted screwhead accessible at the rear of the cover. By rotating the screw, the light intensity in the indicator unit can be made to match the intensity of the other instrument lights on the panel. This control may be connected in series with the aircraft's master dimmer control. Figure 13-23 shows an electrical schematic diagram of the angle of attack system.

For additional information on a particular type of angle of attack system, consult the handbook for the system.

The *Naval Aeronautic Publications Index,* NavAer 00-500, contains a listing of the handbooks that apply to the various systems.

QUIZ

1. The type designation of a relay is RY 3150-C-2. What type relay is it?
   a. Armature type, differential, operating temperature from -65° C. to +200° C., enclosed but not sealed relay
   b. Armature type, ratchet, operating temperature from -55° C. to +85° C., relay
   c. Armature type, sensitive, operating temperature from -65° C. to +125° C., sealed relay
   d. None of the above
2. The stall warning system contains
   a. 4 units
   b. 3 units
   c. 2 units
   d. 1 unit
3. Contactor relays (power relays) are used to control d-c power circuits of
   a. 30 volts 500 amps
   b. 28 volts 600 amps
   c. 27 volts 400 amps
   d. 28 volts 500 amps
4. In the AVP-109C generator control panel the polarized differential relay opens on a reverse current of
   a. 20 amps
   b. 30 amps
   c. 15 amps
   d. 25 amps
5. With the AVP-109C generator control panel installed in a generator system, the voltage across the series winding of the generator at rated load varies between
   a. 1.6 and 2.3 volts
   b. 2.3 and 2.7 volts
   c. 1.8 and 2.5 volts
   d. 2.0 and 2.6 volts
6. When excessive voltage occurs on one of the generators in the AVP-109C generator system, it is removed from the main bus by the
   a. polarized voltage relay
   b. polarized differential relay
   c. overvoltage relay
   d. equalizer disconnect relay
7. The tubular probe of the airstream direction detector is divided into
   a. two parallel chambers
   b. three parallel chambers
   c. four parallel chambers
   d. one chamber

8. The equalizer disconnect relay in a d-c generating and control system connects the regulator equalizer coil to the
   a. first line contactor
   b. equalizer bus
   c. main bus
   d. polarized differential relay
9. The equalizer disconnect relay picks up at approximately
   a. 20 volts
   b. 25 volts
   c. 18 volts
   d. 15 volts
10. In general, a relay is divided into how many basic components?
   a. 2
   b. 4
   c. 1
   d. 3
11. The stall warning system is used to indicate
   a. high angle of attack
   b. medium angle of attack
   c. low angle of attack
   d. all of the above
12. When generators are connected in parallel, if one generator tends to take more of the load than the others, the voltage drop on its series winding will be
   a. lower
   b. higher
   c. remain the same
   d. none of the above
13. In figure 13-6 the two sets of contacts are controlled by
   a. two coils
   b. three coils
   c. one coil
   d. four coils
14. Closing of a polarized relay is determined by the
   a. direction of current in the coil
   b. amount of current in the coil
   c. design of the return spring
   d. size of the core
15. When a generator using a ground and feeder protector relay is delivering current to the main d-c bus (fig. 13-10) the current flow from the generator is first through coil
   a. 2
   b. 3
   c. 4
   d. 1

.6. Refer to figure 13-6. Current through coil *C* at the moment of switch closing is
   a. 250 - 400 amps
   b. 500 - 600 amps
   c. 1,500 - 1,700 amps
   d. 1,000 - 1,200 amps
.7. In the polarized differential relay shown in figure 13-4, coil *B* causes contacts *C* to close at a voltage differential of
   a. 1 volt
   b. 0.75 to 0.85 volt
   c. 0.35 to 0.65 volt
   d. 0.20 to 0.30 volt
18. The number of cams on the central shaft of the airstream direction indicator unit is
   a. 1
   b. 2
   c. 3
   d. 4
19. The average voltage drop across the contacts of a power relay should not exceed
   a. 0.2 volts
   b. 0.1 volts
   c. 0.4 volts
   d. 0.3 volts
20. A relay marked RY 9200-A-1 would be a
   a. latch-in relay
   b. marginal relay
   c. polarized relay
   d. sensitive relay
21. In figure 13-10, which is a typical circuit diagram for a ground and feed protector relay, coils 2 and 3
   a. aid each other
   b. oppose each other
   c. are connected in series with each other
   d. are connected in parallel with coil 1
22. In the generator control panel (type AVP-109C) the polarized voltage relay closes at
   a. 20 volts
   b. 25 volts
   c. 23 volts
   d. 22 volts
23. The airstream direction detector determines the direction of the local airflow in speeds above 90 knots with an accuracy of
   a. 1 degree
   b. 0.1 degree
   c. 0.5 degree
   d. 5 degrees

24. In the dual contactor and feeder protector assembly, if the first set of contacts fail to open, the second set of contacts will open at a reverse current of
   a. 100 amps
   b. 200 amps
   c. 350 amps
   d. 400 amps

CHAPTER 14

SPECIAL EQUIPMENT AND MAINTENANCE INFORMATION

As a senior shop petty officer, one of your most important duties is to maintain a constant quest for ways to improve the efficiency of the men you supervise. There are many ways in which this can be done. For instance, you can obtain and pass on to the men information on and ways of using special test equipment, information concerning troubleshooting shortcuts and maintenance techniques, and so forth. This type of information is usually not found in the *Handbook of Maintenance Instructions* for the aircraft.

This chapter provides information on the operation and use of certain test equipment generally not used daily, but is highly useful when needed. It also includes a few items of information pertaining to special maintenance and troubleshooting problems that may be noted and passed on to your men. There is a vast amount of such information available. It is not practical to list all of it in this training course. The few items and ideas listed here are intended only as a sample of the type of information for which you should watch and listen. For instance, you should be a regular reader of such publications as the *Electronics Digest*, *Naval Air News*, and the various command publications since they contain much information of this nature. Any improvement you

are able to make in the working effectiveness of your men adds directly to the performance record of your whole organization.

CATHODE-RAY OSCILLOSCOPE

Cathode-Ray Tube

The cathode-ray tube is a special type of vacuum tube in which electrons emitted from the cathode are shaped into a narrow beam and accelerated to a high velocity before striking a phosphor-coated viewing screen. The screen fluoresces or glows at the point where the electron beam strikes it, and thus provides a visual means of examining and measuring current and voltage waveforms. Differences between the optimum waveform and the scope pattern indicate that a circuit (and therefore the equipment) is falling below the optimum performance level and that corrective action should be applied. By using the oscilloscope in this manner, difficulties may be pinpointed to a specific circuit or portion of a circuit in a minimum of time.

The tube is also used as the visual indicating device for display information obtained by radar, sonar, radio, direction finders, loran, and television.

The beam of electrons has practically no weight or inertia and follows a straight line unless diverted by an electric or a magnetic field. Cathode-ray tubes are either of two types according to the method of deflecting the electron beam—electrostatic and electromagnetic. The electrostatic type of cathode-ray tube is used in practically all cathode-ray oscilloscopes operating as test instruments. Certain radar and sonar sets use cathode-ray tubes that employ electromagnetic deflection. Focusing or narrowing the beam before deflection is accomplished either by electrostatic or electromagnetic means. In the electrostatic type, the beam is deflected by an electric field set up across the deflection plates by a deflection voltage. In the electromagnetic type the beam is deflected by a magnetic field established by a deflection current in a coil around the outside of the tube.

A simplified arrangement of the construction details of a cathode-ray tube employing electrostatic deflection and focusing is shown in figure 14-1. The cathode, when heated by the enclosed filament, releases free electrons. A cylindrical grid surrounds the cathode and controls the beam intensity as electrons pass through the end-opening of the grid. The control is accomplished by varying the negative voltage on the grid and is called intensity or brightness control. After leaving the grid the electron stream passes through two or more cylindrical anode focusing plates which concentrate the electrons into a narrow beam. The first anode concentrates the free electrons and the second anode accelerates them. The entire assembly including the cathode, grid, and the two anodes is called the electron gun. The electrons emerge from the electron gun at high speed.

The grid helps to narrow the beam but cannot focus it to a sharp point on the viewing screen. The two anodes aid in the focusing action, as shown in figure 14-2. The electric field is established between the anodes. Electrons entering this field converge at point S on the screen. The second anode is positive with respect to the first anode and both are positive with respect to the cathode in order to attract electrons from the cathode and to accelerate them. The impelling force of like charges tends to scatter the electrons, but they are accelerated to such a high speed that the scattering action is not effective in defocusing the beam. Nevertheless the mutual repulsion between electrons determines the sharpness with which a beam may be focused on the screen.

The focus of the electrostatic type of cathode-ray tube is generally controlled by varying the voltage between the first anode and the cathode. This voltage varies the force exerted on the electrons and tends to narrow the beam. Thus, if the screen is observed when the first anode voltage is varied, the beam may be brought to a bright sharp spot.

Focusing in an electromagnetic cathode-ray tube is accomplished by a coil encircling the outside neck of the tube. The coil may be moved along the neck to a limited extent to focus the beam; but the normal method, after the coil is in the proper position, is to vary the current flowing through the coil.

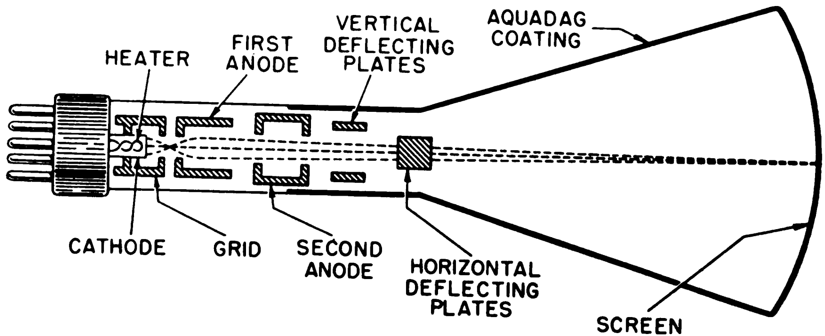


Figure 14-1.—Construction of cathode-ray tube using electrostatic deflection and focusing.

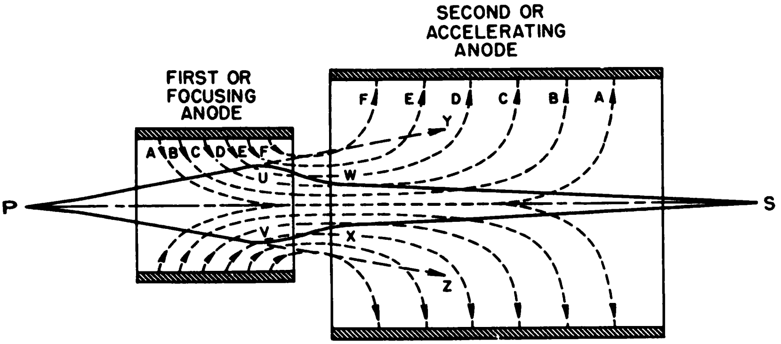


Figure 14-2.—Electrostatic focusing.

Without lateral deflection, the electron gun produces only a small spot of light on the viewing screen. With deflection, the trace of the spot forms a line on the screen. The electrostatic type cathode-ray tube uses two pairs of deflection plates mounted at right angles with respect to each other, as shown in figure 14-3. The vertical deflection plates (*YY'*) deflect the beam in a vertical direction, and the horizontal deflection plates (*XX'*) deflect it horizontally. Both pairs usually function simultaneously. The beam is attracted by the positive plate and repelled by the negative plate as the electrons pass between them. One plate of each pair is usually grounded. To deflect the beam, a positive or negative voltage is applied between the other plate and ground, thus establishing an electric field between the plates. The deflecting force varies with the deflection voltage across the plates and with the field intensity.

If plate *Y* is positive with respect to *Y'*, the beam is deflected upward, striking the screen at *A*. If plate *Y* is negative with respect to *Y'*, the beam is deflected downward, striking the screen at *B*. If there is no deflection voltage across the plates, the beam will strike the screen at *O*. The amount of deflection varies with the deflection voltage across the plates. If plate *X* is positive with respect to *X'*, the beam will be deflected horizontally and strike the screen at *C*. If *X* is negative with respect to *X'*, the beam will strike the screen at *D*.

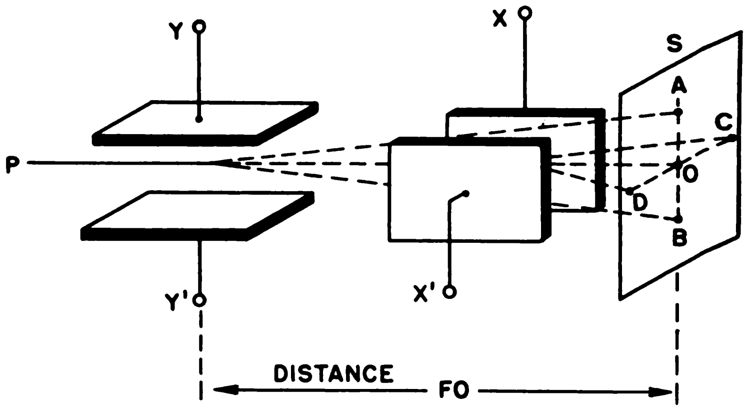


Figure 14-3.—Deflecting plates for electrostatic cathode-ray tube.

Both pairs of plates are mounted near the output end of the electron gun with the vertical deflection plates farthest from the screen. Centering controls are provided, which enable the operator to move the spot to any desired point on the screen.

The electron beam deflection angle is the angle through which the beam may be deflected in any direction from the centerline through the tube. A cathode-ray tube having a 50° deflection angle is one in which the electron beam can be deflected in any direction at an angle of 25° with respect to the centerline. Such tubes are called wide-angle tubes and are constructed with a greater flare and shorter length so that the beam can be deflected through a large angle without striking the tube walls. Wide-angle cathode-ray tubes are used extensively in television receivers.

The length of time that the screen glows or fluoresces at the point where the electron beam strikes it, depends on the material of the phosphor-coating on the screen, and is known as screen persistence. Some cathode-ray tubes have a long persistence screen and others a short persistence, depending on their use. The screen phosphors are designated by the letter "P" followed by a number. Most radar indicator cathode-ray tubes employ *P*1, *P*4, or *P*7 screen phosphors. The *P*1 and *P*4 phosphors have medium persistence and give off green

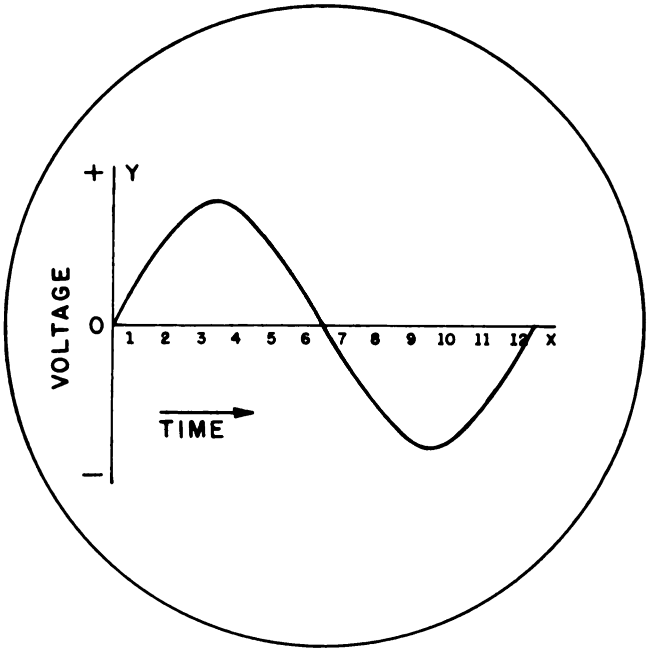
and white light respectively. The 7 screen has long persistence and gives off yellow light.

All fluorescent materials have some phosphorescence, or afterglow, but the duration of the afterglow varies with the material, as well as with the amount of energy in the beam causing the emission of light. A screen material on which the image will linger is desirable for oscilloscopes used for observing nonrepeating or periodic phenomena that occur at a low repetition ratio. In applications where the image changes rapidly, prolonged afterglow is a disadvantage, because it may cause confusion on the screen.

The eye retains an image for about one-sixteenth of a second. Thus, in a motion picture the illusion of motion is created by a series of still pictures flashed on the screen so rapidly that the eye cannot follow them as separate pictures. In the cathode-ray tube the beam is repeatedly swept across the screen and the series of adjacent spots appears as a continuous line. Thus the waveshape of an a-c voltage can be observed on the screen when the a-c voltage is applied to one pair of deflection plates, and simultaneously a second voltage of appropriate characteristics is applied to the other pair of plates.

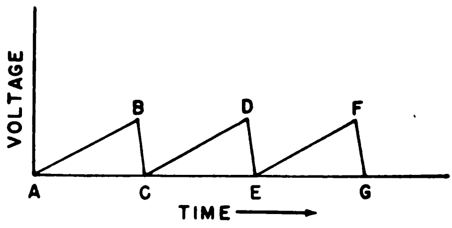
The conventional way of representing voltage or current of sine waveform is shown in figure 14-4 (A). The voltage to be observed is applied across the vertical deflection plates and simultaneously a sawtooth voltage is applied across the horizontal deflection plates. The sawtooth voltage moves the beam from left to right at constant speed to form the time scale along OX; then it returns the beam rapidly to the starting position at the left and repeats the operation. The sawtooth voltage is so named because when plotted against time it resembles a sawtooth as shown in figure 14-4 (B). As the voltage increases from A to B, the beam is swept from 0 to 12 (fig. 14-4 (A)). As the voltage falls from B to C (fig. 14-4 (B)), the beam is quickly returned to its starting position and the process is repeated.

If an a-c voltage of sine waveform is placed across the vertical deflection plates with no horizontal deflection, a single vertical line appears on the screen. The varying rate of change of the voltage is hidden because the vertical movements retrace themselves repeatedly



A

SINE-WAVE VOLTAGE PLOTTED AGAINST TIME



B

SAW-TOOTH WAVEFORM PLOTTED AGAINST TIME

Figure 14-4.—Sine-wave and sawtooth voltage waveforms.

on the same vertical line. Similarly, if a sweep voltage of sawtooth waveform is applied to the horizontal deflection plates in the absence of vertical deflection, a horizontal line is formed and the rate of change of the voltage is obscured. However, when both voltages are introduced at the same time, the vertical motion of the

beam is spread out across the screen to form a sine curve like that shown in figure 14-4 (A).

Oscilloscope Circuits

A block diagram of a cathode-ray oscilloscope is shown in figure 14-5. The horizontal deflection amplifier is a high-gain R-C coupled class A wide-band voltage amplifier that increases the amplitude of the horizontal input voltage and applies it to the horizontal deflection plates. The sweep generator supplies a sawtooth voltage to the input of the horizontal amplifier through a switch that provides an optional external connection. The vertical deflection amplifier increases the amplitude of the vertical input voltage before applying it to the vertical deflection plates. The input to the vertical amplifier appears in magnified form on the viewing screen as a graph of the current or voltage waveform being examined. A rear terminal block provides direct electrical connections to the deflection plates. The direct connections are used, for example, when examining d-c potentials, or high-frequency signals that would be attenuated excessively by the amplifier circuits. The power supply provides all d-c voltages for the tubes including a high d-c potential for the cathode-ray tube.

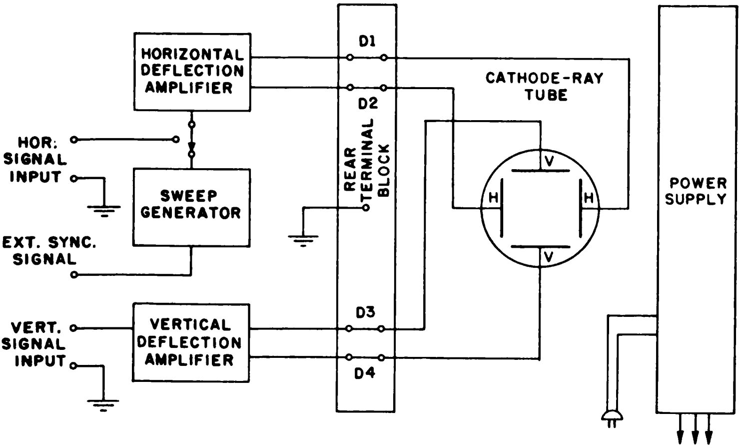


Figure 14-5.—Block diagram of a cathode-ray oscilloscope.

A schematic diagram of an elementary cathode-ray oscilloscope is shown in figure 14-6. The cathode-ray tube employs electrostatic focusing and deflection. *V*1 is the vertical amplifier, *V*2 the horizontal amplifier, and *V*3 the sweep generator. *R*1 is a manual vertical gain control, *R*2 is a manual horizontal gain control, *S*3 is the coarse frequency adjustment for *V*3, and *R*10 is the fine frequency adjustment. An external synchronizing signal may be applied from an external source to the grid of *V*3 when *S*2 is in the EXT. SYNCT. position. *R*3 provides manual control of the sync signal amplitude.

The low voltage power supply includes a conventional full-wave rectifier, *V*4; secondary windings *L*4, *L*5, and *L*6 of the power supply transformer; and the pi-filter (*C*17, *L*13, and *C*18). The cathode of *V*4 is positive with respect to ground. The output voltage (440 volts) is applied to the plate circuits of *V*1, *V*2, and *V*3. The voltage divider (*R*14, *R*15, and *R*19) is connected across the output of *V*4 and supplies +170 volts to the left side of the centering controls (*R*17 and *R*18).

The high voltage power supply includes *V*5 and secondary windings *L*6, *L*7, and *L*8 of the power supply transformer. The output voltage of *V*5 is negative with respect to ground and is applied across the voltage divider (*R*20, *R*21, *R*22, and *R*24). *C*19 filters the output voltage. The tap between *R*20 and *R*21 supplies +170 volts to the right side of *R*17 and *R*18.

The cathode of the cathode-ray tube is connected at -1,000 volts with respect to the ground. The second anode in the cathode-ray tube is grounded, and the first anode is negative with respect to the second anode but both anodes are positive with respect to the cathode. This arrangement provides the necessary accelerating voltage for the electrons in the beam to form a bright spot on the screen. At the same time it prevents defocusing the spot by holding the average voltage across the deflection plates close to the potential of the second anode. The arrangement also introduces a safety factor by removing high voltage from the deflection plates and the associated input terminals on the rear panel.

Capacitors *C*1, *C*2, and *C*3 block any external d-c voltage components from the grids of *V*1, *V*2, and *V*3. Similarly, capacitors *C*7 and *C*8 block the d-c components of plate

voltage from the cathode-ray tube deflection plates and at the same time couple the a-c components to them. *C*9 couples a blanking pulse to the grid of the cathode-ray tube, which blanks out the return trace of the sweep generator. During the time the sweep voltage rises in a positive direction, *C*9 charges at a constant rate through *R*24 and the C-R tube bias is reduced accordingly. As the sweep voltage suddenly falls and snaps the electron beam back to the left side of the screen, *C*9 rapidly discharges through *R*23, driving the cathode more positive, and biases the C-R tube below cutoff so that the return trace is invisible.

The synchronizing voltage applied to the grid of *V*3 stabilizes the screen pattern.

*R*17 and *R*18 are positioning controls that provide manual adjustment of the low d-c voltages that may be applied across the two pairs of deflection plates. The spot is approximately centered on the screen when the voltage between the contact arms of *R*17 and *R*18 is zero. Moving the contact arm of *R*17 to the right makes one vertical plate more negative and thus repels the beam and moves the spot vertically a certain distance on the screen. Conversely, moving the contact arm of *R*17 to the left of the zero position makes the vertical plate more positive. This attracts the beam and moves the spot in the opposite direction.

Applications

OBSERVATION OF WAVEFORMS.—The cathode-ray oscilloscope is generally used to observe voltage waveforms in testing electrical circuits. The electrostatic cathode-ray tube employs voltage sources rather than current to deflect the electron beam. For this reason the electrostatic type of cathode-ray tube is used in test oscilloscopes. The electromagnetic cathode-ray tube is a current-operated device. It is used in certain applications other than general testing, where its properties make it more suitable than the electrostatic tube.

To obtain an accurate representation of the voltage waveform, a few precautions must be observed. For the protection of both the operator and the oscilloscope, the approximate magnitude of the voltages in the circuit

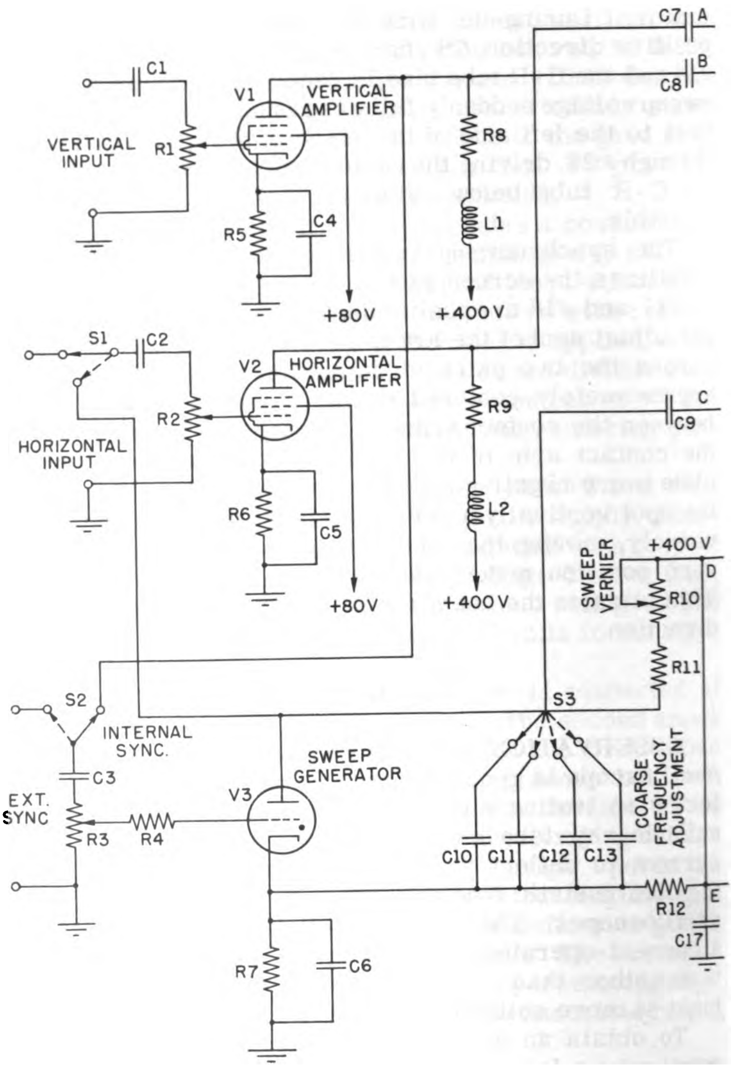


Figure 14-6.—Schematic diagram of an elementary cathode-ray oscilloscope.

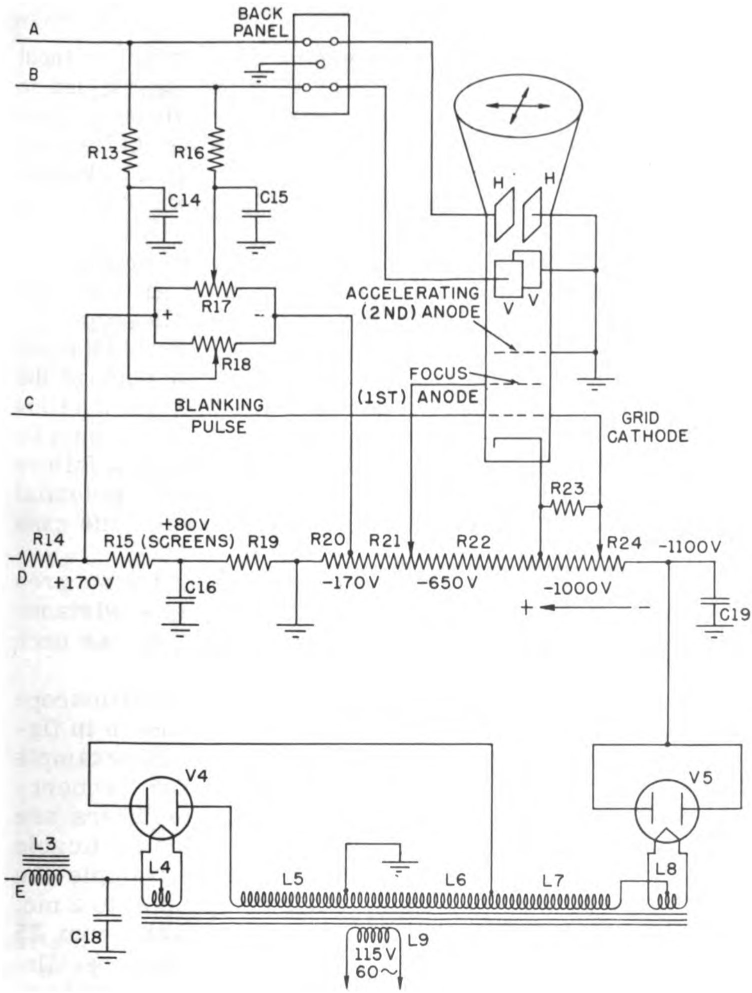


Figure 14-6.—Schematic diagram of an elementary cathode-ray oscilloscope.—Continued

under test must be known. Dependable data can be obtained from the oscilloscope only if its sensitivity and frequency characteristics are known. To make certain that the waveform will not be distorted, it is essential that the manner in which distortion takes place be understood and that precautions be taken to minimize such distortion.

The input to most oscilloscopes is between an input terminal and ground. The input terminal is coupled to the amplifier grid through a capacitor whose voltage rating rarely exceeds 450 volts. Therefore, unless the approximate magnitude of the voltage under test is known, damage to the oscilloscope through breakdown of the input capacitor may occur.

In some cases it may be necessary to observe waveforms in circuits where the voltage is much greater than that which the components within the oscilloscope can withstand. A voltage divider may be used in such instances to reduce the voltage to a value that will not damage the equipment. In any case, it is important that the oscilloscope be adequately grounded—a precaution that must be taken for the protection of the operator, because a failure of some part of the voltage divider can raise the potential of the whole oscilloscope to a dangerous level if the case is not properly grounded.

If a capacitance voltage divider is used, a wise precaution is to shunt each capacitor with a high resistance to maintain the proper voltage distribution across each capacitor.

The range of sweep frequencies in a given oscilloscope is usually indicated on the control panel, as shown in figure 14-7. The sweep frequency generator in this example has a frequency range of 3 to 50,000 c.p.s. The frequency range that the vertical and horizontal amplifiers are capable of amplifying properly is given in the applicable manufacturer's instruction book. In this example the vertical amplifier has a bandwidth from 30 c.p.s. to 2 mc. and the horizontal amplifier has a bandwidth from 25 c.p.s. to 100,000 c.p.s. Generally, only the best oscilloscopes use amplifiers that will amplify voltages whose frequency is below 30 c.p.s. or above 100,000 c.p.s. Oscilloscopes that do not cover as wide a range of frequencies as the one shown in figure 14-7 may be

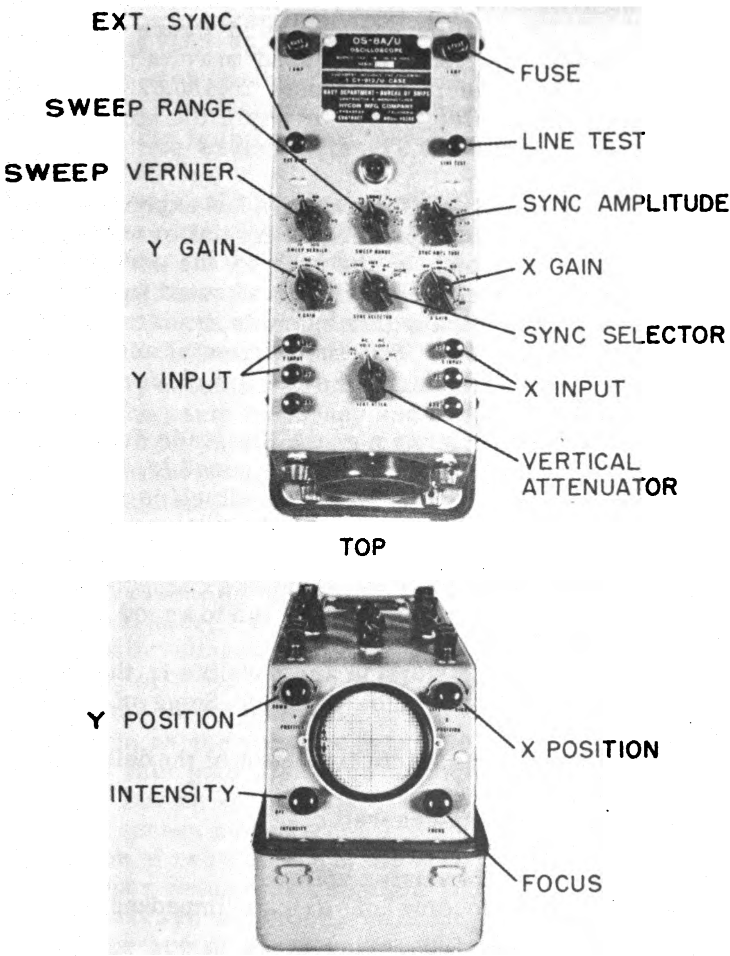


Figure 14-7.—Oscilloscope controls.

satisfactory for most uses; however, distortion is likely to occur when sawtooth or rectangular waveforms of a high recurrence rate are investigated.

The deflection sensitivity may be expressed as the distance in millimeters that the spot is moved on the screen when 1 volt is applied across one pair of deflection

plates. The deflection sensitivity of the vertical deflection plates in the oscilloscope shown in figure 14-7 is 0.528 millimeters per volt. Expressed in volts per inch of deflection, the deflection becomes 25.4/0.528, or 48 volts per inch. The deflection sensitivity of the horizontal plates in this example is 0.379 millimeters per volt, or 67 volts per inch.

The deflection sensitivity may also be expressed as the input voltage to the amplifier (horizontal or vertical) for a deflection of 1 inch of the spot on the screen. In this case the amplifier gain control is adjusted to a suitable value that is arbitrary (for example, midscale). In the example of figure 14-7, both the horizontal and vertical deflection sensitivity are 0.1 volts r.m.s. for 1-inch peak-to-peak deflection.

To avoid pickup of stray signals the leads from the circuit under test should be as short as possible, and they should be shielded. The cathode-ray tube itself is shielded by the special type coating on the inside of the tube and a metal shield on the outside. A common side of the oscilloscope circuits is grounded and should be connected to a ground point in the circuit under test and to a good external ground connection.

Several causes of distortion are possible in the production of a cathode-ray tube display. Some of these causes are:

1. Exceeding the bandwidth limitation of the deflection amplifiers.
2. A defective sweep generator.
3. Excessive flyback time.
4. Excessive synchronizing voltage.
5. Oscilloscope loading of a high impedance test circuit.
6. Oscilloscope capacitance shunting of video amplifier test circuit.
7. Use of a variety of oscilloscopes and test leads on one equipment.
8. Improper shielding of test leads.

Lissajous Figures

If a sinusoidal alternating voltage is applied only to the horizontal deflecting plates of a cathode-ray tube, a single horizontal line will be seen on the screen.

The beam, starting at the left of the screen, moves slowly at first, then rapidly across the center, and slows down to stop at the right of the screen, after which it reverses its direction, again traveling slowly at the ends and rapidly in the center. But the eye sees only a single straight line.

If, next, an alternating potential is applied to the vertical deflecting plates alone, then a similar vertical line will appear on the screen.

The patterns that will appear on the screen when alternating voltages are applied simultaneously to both the X and the Y deflecting plates will now be considered.

First, assume that the alternating voltages have precisely the same frequency and are in the same phase. In other words, they both pass through their zero values at the same moment and they both reach their crests at the same moment.

In figure 14-8, the horizontal wave is shown at X and the vertical wave is shown at Y. Starting at zero voltage in both cases, the spot is at the center of the screen. A moment later, 1 in the figure, the spot has been moved upward by voltage Y and to the right by voltage X. After one-quarter of a cycle, it is at the upper right corner of the screen, 2 in the figure.

Then, as the voltages decrease, the spot of light retraces this path along the straight line to the central point. During the negative half cycles the spot of light on the screen moves from 0 to 6 and back to 0. Thus, the addition of two voltages in the same phase and of the same frequency results in a straight line on the screen. The line makes an angle of 45° with the X and Y axes when the voltages are of equal value. If two voltages are not of equal amplitude, the straight line will be produced, but it will occur at an angle differing from 45°.

Next, consider the case when the two voltages have exactly the same frequency and amplitude, but start a quarter of a period out of phase with respect to each other. The application of these two voltages to the X and Y plates results in a movement of the spot of light on the screen in a circular pattern as shown in figure 14-9. If the two voltages are not of equal amplitude, an ellipse will be formed on the screen.

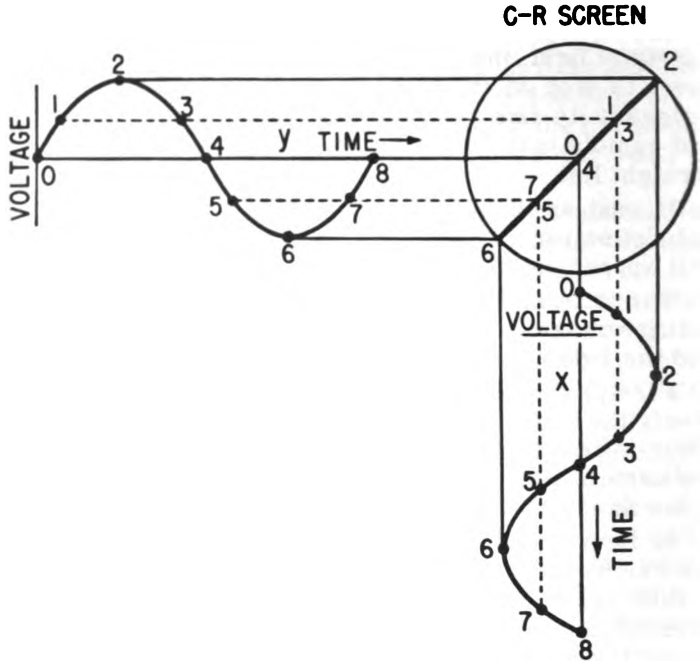


Figure 14-8.—Two sine waves of the same frequency and phase applied to X and Y plates move the spot along a straight line.

Next, consider the case when the voltages on the *X* and *Y* plates are of equal amounts, start in phase with other, but differ in frequency in the ratio of 2 to 1. Figure 14-10 shows how the figure-8 pattern is compounded from these two simple harmonic motions.

It is an interesting problem to work out the shapes of the pattern on the screen when alternating potentials of different amplitude ratios, frequency ratios, and phase differences are applied to the deflecting plates. Figure 14-11 illustrates a few of the possibilities. Conversely, when a particular pattern is noted on the screen, figure 14-11 helps to tell the frequency, amplitude, and phase relationship of an unknown voltage with respect to a standard. The various figures shown are known as Lissajous patterns.

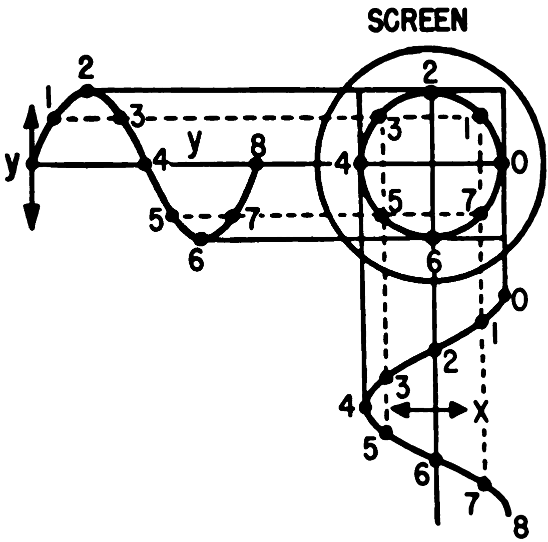


Figure 14-9.—A circle is obtained when the two waves have the same amplitude and frequency but are not in phase.

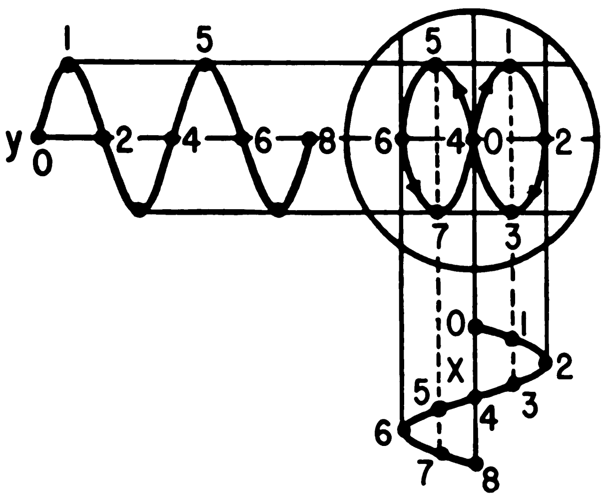


Figure 14-10.—The voltages on the deflection plates are equal in amplitude and phase, but the frequency applied to Y is twice that on X.

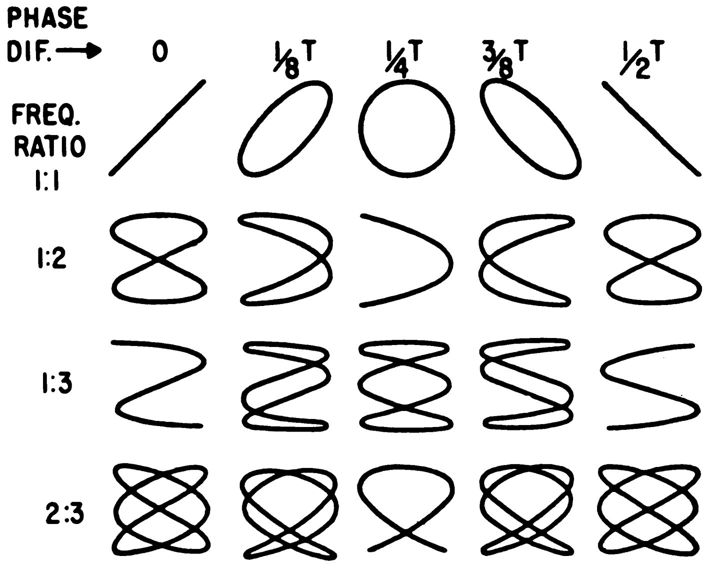


Figure 14-11.—Some Lissajous patterns.

VACUUM TUBE VOLTOHMMETER

Vacuum tube voltohmmeters have a very high input impedance. They utilize the power gain of a vacuum tube to produce meter movement without loading the source of the voltage to be measured. They may also be used for measuring resistance. This is done by comparing the resistance to be measured with a fixed resistance. The unknown resistance is connected in series with a resistance and a fixed voltage. The voltage appearing across the unknown resistance is proportional to its ohmic value. The voltohmmeter resistance scale is calibrated in ohms rather than in volts.

The vacuum tube voltohmmeter discussed in this chapter utilizes this principle of operation. Figure 14-12 shows a typical vacuum tube voltohmmeter. You may not find this particular meter in your shop, but, with all probability, the one that you use will be similar.

The vacuum tube ohmmeter shown in figure 14-12 is designed to measure d-c voltages ranging from 0.1 to 1,200 volts, r.m.s. sine wave voltages from 0.1 to 1,200

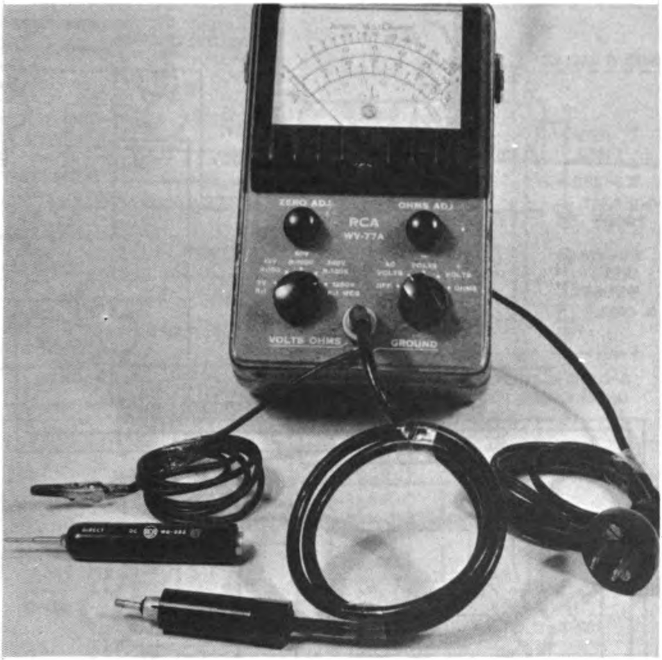


Figure 14-12.—Vacuum tube voltohmmeter.

volts, and resistance values from 0.2 ohms to 1,000 megohms.. The frequency range of this meter when measuring a-c voltage is up to 3 megacycles. There are other types of vacuum tube voltohmmeters that have a frequency range up to 300 megacycles. A meter of this type would only be used in radio and radar circuits. Since the Aviation Electrician will be concerned with circuits that have a much lower frequency range, a meter having a frequency range up to 3 megacycles is adequate.

Figure 14-13 shows an electrical schematic of the vacuum tube voltohmmeter shown in figure 14-12. An explanation of this circuit will help you to understand the operation of this meter and also any other vacuum tube voltohmmeter, since all are basically the same.

The meter utilizes a push-pull, amplifier-type, d-c bridge circuit. This circuit possesses good linearity response, good stability, and high input impedance. When no voltage measurement is being made, the cathode

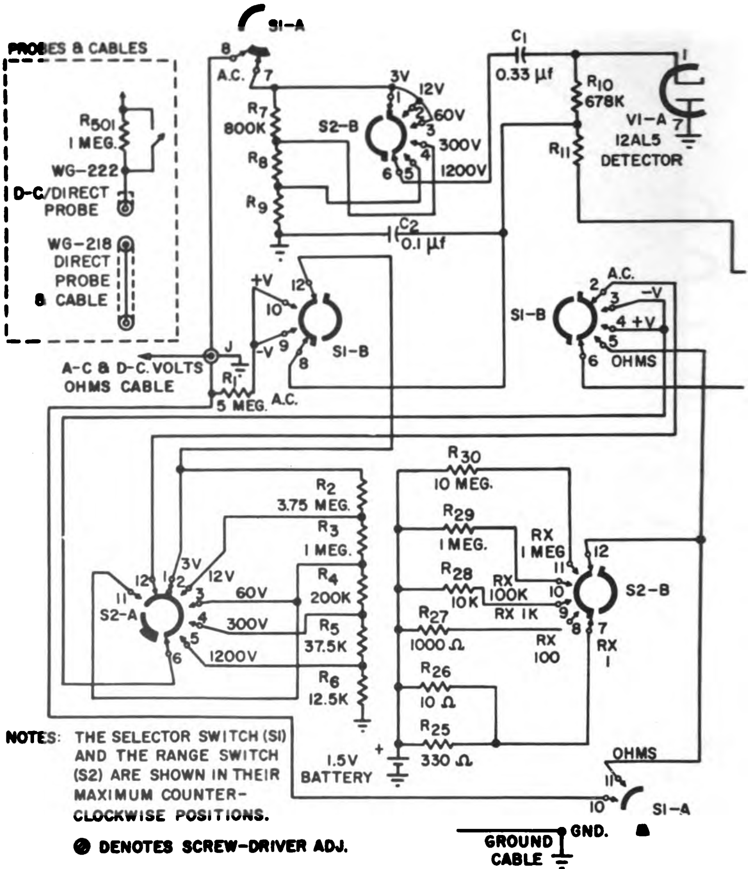


Figure 14-13.—Electrical schematic of vacuum tube voltohmmeter.

currents through both halves of *V2* are equal; thus, the meter reads zero, since its bridge is balanced.

Two rotary wafer switches are mounted on the front of the vacuum tube voltohmmeter. One of these switches allows the operator to select what is to be measured. The quantities that can be measured are a-c volts, minus volts, positive volts, or ohms. The other switch is a range switch. It enables the operator to select the operating limits for the particular quantity to be measured.

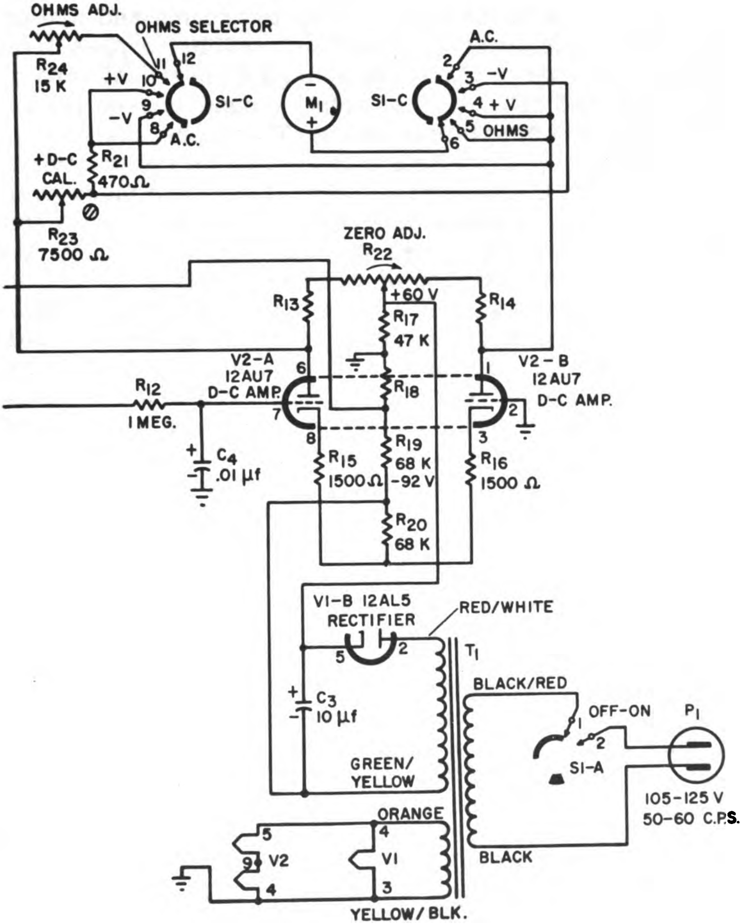


Figure 14-13.—Electrical schematic of vacuum tube voltohmmeter.—Continued

Assume that an a-c voltage whose range will not exceed 3 volts is to be measured. The switch selection of *S2B* is as shown in figure 14-13. The a-c voltage to be measured will be rectified by *V1A* (12AL5 detector). This rectified voltage appears across resistors *R*10, *R*11, *R*12, and *R*18. Figure 14-14 shows a simplified schematic of this circuit. The a-c voltage to be measured is applied across the test cables. Negative alternations pass directly

across *V1A*, from cathode to plate to ground, and are not measured. Positive alternations, unable to pass from plate to cathode in *V1A*, pass instead from ground through *R*18, *R*11, and *R*10. At this point, ground is negative and the upper end of *R*10 is positive. Therefore, the junction of *R*10 and *R*11 is positive with respect to the junction of *R*11 and *R*18. Consequently, the grid of *V*2*A* is made positive, while its cathode is made more negative, so that current increases across *V*2*A* and through *R*13. At the same time, the junction of *R*11 and *R*18 is positive with respect to ground. As a result, the cathode of *V*2*B* is made positive with respect to its negative ground-connected grid, and current decreases through *V*2*B* and *R*14. The unequal currents through *R*13 and *R*14 cause unequal voltage drops across them, so that a difference of potential exists between the plates of *V*2*A* and *V*2*B*. This difference of potential, which is proportional to the magnitude of the voltage being measured, causes meter current (and thus pointer deflection) to also be proportional to the voltage being measured.

When measuring d-c voltage (minus or plus), selector switch *S*1 is positioned either to the minus or plus position, depending on the polarity of the d-c voltage to be measured. Selector switch *S*2 is then positioned to the range of voltage to be measured (3 to 1,200 volts d. c.). Figure 14-15 shows a simple schematic of the d-c voltage measuring circuit.

The total amount of voltage to be measured appears across the voltage divider network *R*2, *R*3, *R*4, *R*5, and *R*6. However, regardless of its magnitude, a maximum of only 3 volts is ever applied across *V*2*A*'s grid circuit, comprised of *R*12 and *C*4. Any voltage greater than 3 volts would cause meter damage. When a large voltage is being measured, proper grid voltage is obtained by picking off a small portion of voltage from the voltage divider. If the d-c voltage to be measured is not in excess of 3 volts, switch *S*2*A* is set at position 1, and all the voltage across the divider is applied to the grid circuit of *V*2*A*. On the other hand, if a maximum of 1,200 volts is to be measured, *S*2*A* is set at position 5. The entire 1,200 volts is dropped across the voltage divider, but only 3 volts of this is dropped across *R*6. As a result, the voltage applied to the grid circuit is still only 3 volts. Intermediate

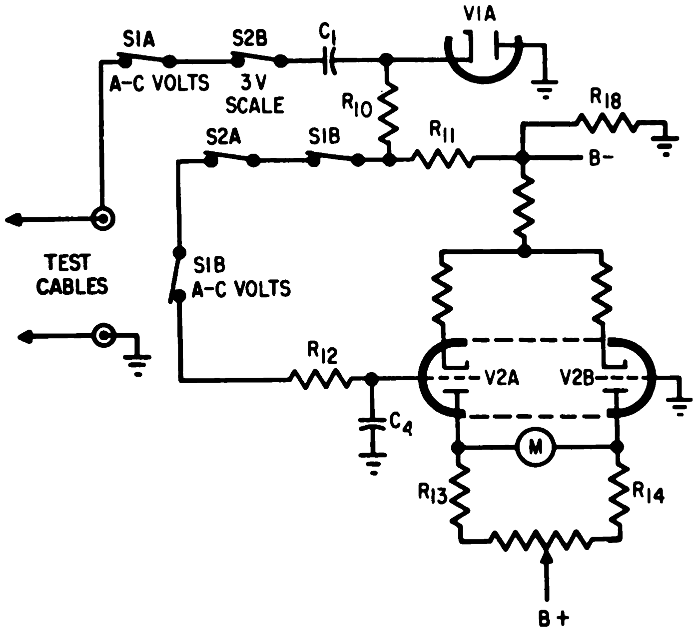


Figure 14-14.—Simplified vacuum tube voltohmmeter bridge circuit.

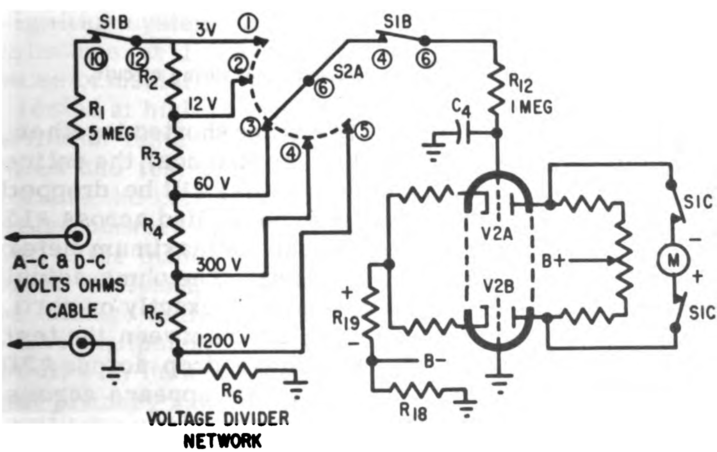


Figure 14-15.—Simplified d-c voltage measuring circuit.

voltages are measured by selecting intermediate positions on *S2A*. This voltage is interpreted into meter pointer deflection in the same manner and by the same tube and resistors as described for measuring a-c voltage.

An unknown resistance may be measured by connecting it in series with a known resistance and voltage. This principle is applied in the simplified resistance-measuring circuit shown in figure 14-16.

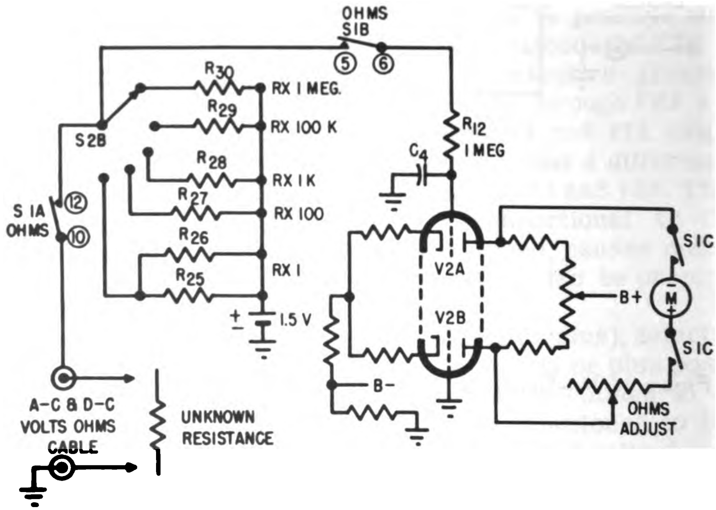


Figure 14-16.—Simplified resistance-measuring circuit.

If the test cables in figure 14-16 are shorted together, and *S2B* is set at any position (*R*30 for instance), the entire known testing voltage (1.5 battery volts) will be dropped across *R*30. This voltage will also be applied across *R*12 and *C*4 in *V2A*'s grid circuit. This causes maximum meter deflection, which indicates zero ohms. The ohms-adjust rheostat may be used to set the pointer exactly on zero. When an unknown resistance is placed between the test cables (in series with *R*30), the voltage drop across *R*30 decreases and the difference in voltage appears across the unknown resistance. Since the grid of *V2A* is sensitive only to the voltage of *R*30, the addition of the unknown resistance causes a decrease in positive grid voltage. This causes a decrease in tube conduction and meter deflection.

The ratio of voltage drop across $R30$ to the voltage drop across the unknown resistance is directly proportional to their relative ohmic values. Consequently, tube conduction and meter deflection is inversely proportional to the ohmic value of the unknown resistance. When making resistance measurements, switch $S2B$ should be set at a resistance value that is nearest to that of the unknown resistance. For instance, if the unknown resistance is a thousand times as great as the selected resistance in the meter, pointer deflection would be only 1/1,000 of the scale. A movement this small would be useless for obtaining an accurate reading. However, if the selected resistance and the unknown resistance are approximately equal, pointer deflection will be approximately midscale. On this portion of the scale, more accurate readings are obtained because the scale increments are widely spaced.

HIGH-VOLTAGE INSULATION TESTER

Several types of high-voltage insulation testers are currently in use. All are similar in many respects. They are designed for the purpose of detecting or measuring leakage paths through or across high-voltage insulation. Spark-plug cables, distributors and various other parts of ignition systems can be tested for adequate insulation resistance at the operating voltages. Many different pieces of insulation other than ignition equipment can also be tested at high voltage. Figure 14-17 shows a typical insulation tester. The unit is portable and connecting cables and test leads are stowed in the cover. It will measure the insulation resistance in megohms at any d-c voltage between 2,000 and 15,000 volts. The voltage applied to the insulation will drop more or less in proportion to the leakage current, thereby preventing destructive damage to the part being tested.

The equipment consists of a voltage doubler rectifier circuit with indicating meters and control circuits. The input primary supply voltage may be either 117-volt, 60-cycle a.c., single phase, or 24-volt d.c. (battery source) at 3.3 amperes. When a 24-volt battery source is used, this d-c supply is converted to 117 volts a.c. by a vibrator type inverter contained in the unit.

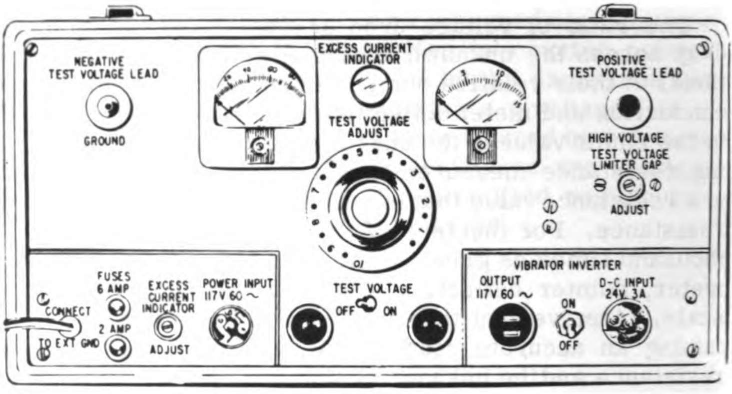


Figure 14-17.—Insulation tester.

The unit's high-voltage transformer is energized by alternating current supplied through a continuously variable autotransformer (commonly called a VARIAC). The secondary of the high-voltage transformer produces a-c voltages from 0 to 10,000 volts r.m.s., depending upon the setting of the VARIAC. High-voltage direct current is produced by means of two high-voltage capacitors and two half-wave rectifiers connected in a voltage doubler circuit. Direct-current voltages from 0 to 15,000 are available. The two half-wave rectifiers are of the cold cathode type and require no filament power or any warmup time.

The output of the voltage doubler circuit is connected to an adjustable ball-type spark gap through a 7,500-ohm, 25-watt wire-wound resistor. One side of the spark gap is grounded to the equipment panel.

The voltage at which the spark gap breaks down (sparks) can be adjusted very closely to the desired maximum voltage to be applied to the equipment being tested. In the event of an input supply voltage surge or should the operator turn the VARIAC too high, a spark jumps across the safety gap, short-circuiting the output test lead circuit. This prevents applying excessive voltage to the equipment being tested. The gap can be set by a screw adjustment on the front panel, to break down at any voltage desired.

When the output voltage exceeds the breakdown voltage of the safety gap by a slight amount, short bursts of

sparks jump across the gap. If the voltmeter, located on the front panel, is read just before the spark occurs, this reading indicates the maximum voltage that can be applied across the equipment being tested. For example, if you want to apply 10,000 volts to the part being tested, the spark gap should be set to arc at about 11,000 volts. A neon indicating lamp, located on the front panel, lights up every time the spark gap breaks down. The operator is protected from shock after turning off the equipment by means of a high-voltage capacitor discharge switch that is mechanically linked to the TEST VOLTAGE switch.

For detailed information concerning the description, operation, and maintenance of a tester, consult the instruction handbook that has been published for that particular piece of equipment.

SPECIAL MAINTENANCE PROBLEMS

As the ceiling for aircraft on extended flights has been raised higher and higher, many new types of operating and maintenance problems have developed. Some of the various types of equipment involved are generators, voltage regulators, electric motors, and solenoids. Electric brushes on generators, inverters, electric motors, and other rotating electrical machinery wear away very rapidly at high altitude (around 40,000 feet). Special brushes have been developed that have longer life at high altitude. Thus, it is advisable to use the proper type brushes and to check them more frequently when high altitude flying is being performed.

While most switches will break a circuit safely at sea level, their contacts may burn and in some cases even melt at high altitude. It has been found that double-break contact switches somewhat alleviate this fault. Since electric and electronic systems use special design switches for high altitude operation, when making a replacement it is necessary to use the proper type.

Other items that often fail during high altitude flights are electrical plugs and receptacles. A voltage breakdown occurs between the pins and shell along the surface of the insulating material. The result is a burned plug. This happens because the breakdown voltage is less at high altitude. For example, the breakdown voltage for a

1/4-inch air gap is about 3.7 times greater at sea level than at 40,000 feet.

This condition may be overcome by sealing the connector with a potting compound. This reduces the probability of arc-over between pins or between pins and the shell of the electric connector since the dielectric characteristics of the connector are improved. This sealing compound will also protect the connectors from corrosion or contamination by excluding metallic particles, moisture, and aircraft liquids. For information regarding the application of a sealing compound consult the current publication on this subject.

Environmental Considerations

In recent years the effect of environmental conditions upon the operation of electronic and electrical equipment has greatly increased the maintenance problems of the electrician. These peculiar conditions may be grouped under the major headings of altitude, temperature, and humidity. At the extremes of these conditions special maintenance and operating procedures are required. Equipments required to function at these extremes frequently fail due to the effect of decreased air density, radical temperature changes, and moisture.

Continuous damp, warm air causes condensation of atmospheric moisture within equipment unless units are hermetically sealed or the interiors are maintained at a temperature higher than surrounding atmospheric temperatures. Condensed moisture forms leakage paths and causes corrosion. These climatic conditions promote rapid fungus growth which in itself has a corrosive effect on materials, such as wire, switch contacts, and other metal parts.

ADVERSE CLIMATIC CONDITIONS AND THEIR EFFECTS.—Humidity is a term describing the amount of water vapor in the air. It is usually expressed as a percentage of the total amount of water the air can hold at a given temperature. Thus, 50 percent means the air contains one-half the total water it can hold, and 100 percent means it contains all it is capable of holding. Air can hold more water as its temperature increases. In tropical areas the humidity varies between 60 and 100 percent.

This high humidity accounts for the condensation of moisture, or sweating, on various parts of electronic equipments when they undergo temperature changes. Condensed moisture on insulating materials reduces their insulating qualities and results in arc-overs and shorts between terminals. The water vapor also penetrates into the body of insulation, is absorbed, and causes similar effects. High humidity also causes corrosion of metals. Other sources of moisture which cause deterioration include fog, salt spray, and rain.

In general, equipment may encounter extreme temperatures, ranging from minus 65° F. to a maximum of 135° F., under various climatic conditions of high humidity, fog, rain, salt spray, salt air, cold, insects, fungi, and dust. High temperature and moisture vapor cause rapid corrosion. Fungus and bacterial growths produce acids and other products which speed corrosion, etching of surfaces, and oxidation. This interferes with the operation of moving parts, screws, and so forth, and causes dust between terminals, capacitor plates, and other parts, which produces noise, loss in sensitivity, and arc-overs.

Variations of temperature cause moisture to be breathed through any small cracks, pinholes, or vents in the equipment. As the temperature rises, the air inside a piece of equipment expands and it is expelled, in part, through the openings and vents. When the temperature falls, the air inside the equipment contracts and outside air is admitted through all openings and vents. The moisture which is breathed destroys the insulating qualities of dielectrics and corrodes metals.

Fungus is a form of plant life which feeds on materials of vegetable and animal origin including paper, cotton, and so forth, and such things as dead insects and other fungi. These may be spread by wind, dust, dirt, and insects, such as ants, flies, and mites. Growth may take place on materials other than those of organic origin if a spot of dust or other nutrient substance is present. Fungi thrive in the high humidities and temperatures. Fungus growth causes decay, accelerates the deterioration of insulating materials, and short circuits items such as relays, jacks, and keys. The inclusion of a fungicidal compound in the manufacture of the equipment retards the growth of these fungi.

CLIMATIC DETERIORATION PREVENTION.—Most new equipment is given a climatic deterioration prevention treatment which provides a reasonable degree of protection against fungus growth, moisture, corrosion, salt spray, insects, cold, desert heat, and so forth. The treatment involves the use of a lacquer or varnish coating material applied with a spray gun or brush. Detailed instructions dealing with this treatment may be found in the *General Instructions Handbook*, T. O. No. 16-1-41.

Radio Noise Interference

Suppression of radio interference is a task of first importance to maintenance personnel. The problem has increased in proportion to the complexity of both the electric system and the electronic equipment. The aircraft, the engine, the electric system, and the electronic equipment are involved in the problem. Almost every component of the aircraft is a possible source of radio interference, which is the main factor in preventing the operation of receivers at full sensitivity. All personnel concerned should be familiar with the problem of radio noise and how to eliminate it.

The overall effect of radio interference of any kind is to impair or deteriorate the performance and reliability of radio and electronic sets or systems. The interference may act directly by actual deterioration of the equipment response, or indirectly by wearing down the patience and tolerance of the human operator. Either way, the result is the same, since combat efficiency is materially reduced.

You should know the following:

1. What radio interference is.
2. Where the interference originates.
3. How it gets into equipment.
4. How to identify it.
5. How to suppress it at its source.
6. How to segregate its path of entry into a receiver.
7. How to prevent its entry into a receiver.
8. What considerations enter into the design of an interference-free equipment.
9. How to position and install electrical and electronic devices.

This information is presented in detail in the publication, *Reduction of Radio Interference in Aircraft*, NavAer 16-1-521. Some of the most important of this information will be presented briefly in the following pages.

SOURCES OF RADIO NOISE.—The origin or sources of radio noise are divided into three general groups. These are atmospheric static, precipitation static, and manmade radio noise.

ATMOSPHERIC STATIC, or "atmospherics" is a burst of RF energy caused by electrical discharges in the atmosphere. Although the frequency spectrum of atmospheric static is very wide, only frequencies in and below the high-frequency band propagate far enough to be very troublesome at long distances from the electrical disturbance. Therefore, UHF and VHF receivers are seldom troubled by atmospheric static. Reduction of such static is obtained by use of frequency modulation, directional antennas, and noise-limiter circuits. Frequency modulation is not used extensively in aircraft radio communication because of the bandwidth requirements.

PRECIPITATION STATIC is caused by the development of large static charges on the aircraft when it is flown through snow, rain, ice crystals, or dust clouds. An aircraft can build up a charge of several hundred thousand volts in a few seconds. The resulting high voltage gradients at extremities and sharp points exceed the breakdown strength of air and cause noisy corona discharges. The conventional radio antenna, which must stand away from the body of the aircraft to be of effective height, is exposed to high electric fields. This means that corona discharges occur first in the antenna system, the very place that is most sensitive to noise. Precipitation static is reduced by using a completely insulated antenna system—that is, by using highly insulated wire instead of bare wire, and by insulating all connections and supports for the antenna wire. Precipitation static is reduced also by eliminating all sharp metal projections from the aircraft and by installing dischargers, which quietly discharge accumulated static charges at a high rate. A discharger consists of silver-impregnated cotton wicking encased in a flexible plastic tube with an aluminum mounting lug. The many fine high-resistance fibers provide a multitude of discharge points. The resulting

discharges are quiet up to very high currents. For detailed information on precipitation static refer to NavAer 16-1-518, *Handbook Installation and Maintenance Instructions, Anti-Precipitation Static System*.

The effect of precipitation static is a loud hissing or frying noise from the speaker or headset of radio equipment and interference (grass) on the picture tube of visual output receivers. As an AE you should not be too concerned with precipitation static since it is produced only when the aircraft is flying. Also, the preventive measures that are taken are the primary responsibility of other ratings. You should be aware of its characteristics for there is the probability that you will be asked to correct for radio interference that is caused by precipitation static. Unless you know its characteristics you will not be able to determine that the equipment for which you are responsible is not causing the trouble.

The principal sources of manmade radio interference in aircraft are rotating electrical machinery, switching devices, pulsed electronic equipments, transmitter spurious emission, ignition systems, propeller control systems, receiver oscillators, nonlinear elements, a-c power lines, and voltage regulators. As an AE you will not be concerned with all of these sources. Those with which you should be familiar will be briefly discussed.

1. Rotating electric machines are a major source of radio interference. The types of interfering voltages generated by d-c machines are: (1) Switching transients as the brush moves from one commutator bar to another. This is usually called commutation interference; (2) Random transients caused by varying contact between brush and commutator. This is usually called sliding contact interference; (3) Audiofrequency hum (commutator ripple), and (4) Radiofrequency and static charges built up on the shaft and rotor assembly.

Direct-current motors used in aircraft systems are of three general types: series wound, shunt wound, and permanent magnet field. The field windings of both series- and shunt-wound motors afford some "padding" or filter action against transient voltages generated by the brushes. The permanent-magnet motor's lack of such inherent filtering makes it a very common source of interference. It must be emphasized that the size of

a d-c motor has little bearing upon its interference generating characteristics. The smallest motor aboard may well be the worst offender.

The output of an ideal a-c generator is a pure sine wave. A pure sine wave voltage is incapable of producing interference except at its basic frequency. However the ideal waveform is difficult to produce, especially in small machines. Practically all types of a-c power generators currently used in naval aircraft have been proven to be potential sources of interference at other than the output power frequencies. This interference is produced in the form of (1) harmonics of the power frequency, caused by poor waveform, (2) commutation interference (series-wound motors), and (3) sliding contact interferences (alternators and series-wound motors). It should be noted that a-c motors that do not use brushes are almost never sources of interference.

2. Switching devices make abrupt changes in electric circuits. Such changes are accompanied by transients capable of interfering with the operation of radio and electronic systems. The simple occasionally operated manual switch is of little consequence as a source of interference. Examples of frequently operated switching devices capable of appreciable or serious interference are relays, vibrators, and thyratrons.

Since relays are used almost exclusively to control large amounts of power with relatively small amounts of power, they are always potential interference sources. This is especially true when they are used to control inductive circuits. Relay actuating circuits should not be overlooked as interference sources, because even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the controlled circuit.

Induction vibrators are essentially double-pole double-throw relays which operate at a constant rate. As in any induction type switch or relay, there are two sources of switching transients, the inductive field contacts and the switching contacts. The output waveform of the vibrator is essentially rectangular at some audiofrequency. Its harmonic content is high and filtering is difficult.

Because of its interfering capabilities, the vibrator is seldom used as a radio power source in naval aircraft except for certain commercially available radio equipments found in small auxiliary aircraft. The principal use of inductive vibrators in naval aircraft is in connection with jet engine ignition systems.

Thyratrons are gas filled, grid controlled, electronic switching tubes which are used for many purposes. Among the most common uses are keyer tubes in radar modulators, rectifiers in regulated power supplies, rectifiers in servo systems, and relay applications. The current flow in a thyratron is either all ON or all OFF; there is no in-between. Since the time required to turn a thyratron ON is only a few microseconds or less, current waveforms in thyratron circuits are always steep fronted. As a result, they are rich in radio interference energy.

3. Ignition systems for internal combustion engines produce pulses of energy capable of interfering with radio reception at all frequencies in current use. The physical layout of the ignition's distribution system is such as to offer a very favorable radiation system. The lengths of wire between the distributor and the plugs become very effective antennas at wavelengths shorter than about ten times the length of the lead. Further, the radial arrangement of the wires assures polarization in all planes.

Unless effective preventive action is taken, ignition systems are highly potent sources of radio interference capable of complete destruction of radio reception within their effective fields. Fortunately, the problem of ignition interference is a very old one with a long history of development, effort, and improvement. Modern aircraft engine ignition systems are completely enclosed in metallic shielding harnesses. These shielding harnesses are so effective (when properly maintained) that the ignition interference problem has been reduced to a secondary problem of proper maintenance.

4. Propeller systems, whether hydraulically or electrically operated, are potent generators of radio interference. This interference may be derived from propeller pitch control motors and solenoids, governors and associated relays, synchronizers and associated relays,

de-icing timers and relays, and inverters for selsyn operation.

Propeller control equipments generate clicks and transients as often as 10 times per second. The audio-frequency envelope of commutator interference varies from about 20 to 1,000 c.p.s. The propeller de-icing timer generates intense impulses at a maximum rate of about 4 per minute.

Values of current in the propeller systems are relatively high. The generated interference voltages are therefore severe. They are capable of producing moderate interference at frequencies below 100 kc. and above about 1 mc., with severe interference at frequencies that lie between these extremes.

5. A nonlinear element may be defined as a conductor or semiconductor whose resistance or impedance varies with the voltage applied across it. Nonlinear elements that may cause radio interference in aircraft, in the order of their commonness, are overdriven vacuum tubes, oxidized or corroded joints, cold solder joints, and unsound welds. In the presence of strong signals a nonlinear element behaves as a detector or mixer, producing harmonics and sum and difference frequencies from signals applied to it.

6. Alternating-current power sources produce radio interference of a broadband nature. In a-c powered equipments, a-c hum may appear at the power frequency or at the rectification ripple frequency. The rectification ripple frequency is twice the power frequency times the number of phases. Normally, aircraft systems utilize only single- and three-phase sources at 400 c.p.s. Full-wave rectification of single-phase, 400 c.p.s. power gives a ripple frequency of 800 c.p.s.; a three-phase source yields 2,400 c.p.s. This ripple can produce interference varying from annoyance to complete unreliability of equipment, depending on its severity and its coupling to susceptible elements.

7. Electromechanical and carbon-pile voltage regulators are used in naval aircraft.

The electromechanical regulator is common in older types of aircraft. It is essentially a fast acting relay which switches resistance in and out of the generator field coils to maintain a nearly constant output voltage.

As an interference source, it has all the characteristics of a vibrator except regularity. Most of its interference voltage is produced by arcing at the contact points.

The carbon-pile regulator controls the generator field resistance by magnetically varying the compression of a stack of carbon wafers. If properly adjusted, no arcing occurs and the only interference voltage generated is a result of thermal agitation within the carbon pile. It is seldom severe. This type of regulator is not a serious source of interference.

Manmade radio noise is caused by electrical transients which occur during the operation of electrical or electronic equipment. In brief, manmade radio noise will be generated whenever an electrical circuit is opened or closed abruptly, such as by a relay, commutator, or other make-and-break devices. A similar condition exists when large amounts of current are periodically and abruptly started and stopped, as in radar circuits. An electric spark is a generator of electrical disturbances which appear to cover the entire radiofrequency spectrum.

SUPPRESSION OF MANMADE RADIO NOISE.—Suppression of radio noise has advanced to the point where the proper application of available techniques will insure that receiving equipment installed in the aircraft will operate at optimum efficiency. The suppression or elimination of manmade radio noise is based on the premise that if manmade it can be man-corrected. Four types of suppression techniques are involved.

Isolation is the easiest and most practical method of radio noise suppression and revolves around the possibility of separating the source of radio noise from the input circuits of the receiving equipments affected. As every radio noise source can be considered a small transmitter, it is obvious that the radio noise source and leads carrying radio noise energy should be kept as far away from receiver antennas or lead-ins as possible. In many cases, the radio noise in a receiver may be entirely eliminated simply by moving the antenna lead-in wire just a few inches away from the source of radio noise. The value of sufficient separation between sources of radio noise and receiver input circuits is not apt to be overemphasized. The isolation method of radio noise suppression is very popular as it has the advantages of not

requiring any additional material or adding any additional weight.

Bonding is a very necessary means of radio noise control. It provides grounding of all insulated conducting objects on the exterior of the aircraft. When conducting objects are not grounded, flight through precipitative weather conditions causes high-voltage charges to build up on those objects. Repeatedly, the voltage gets high enough to spark over to an adjacent ground member or the object discharges to the surrounding air by corona conduction. Either mode of discharge causes considerable radio noise.

Other important functions of bonding are to protect the aircraft and personnel from lightning discharges by equalization of potentials produced which might cause arcs and sparks in the aircraft structure, to provide a homogeneous counterpoise for radio transmission and reception, to provide power current return paths, and to provide a short path for bypassing RF noise. All electronic equipments should be grounded to the aircraft structure. This will be done by using short bond straps or by sheets of high conductivity (copper or aluminum) metal where it is impossible to use a short bond strap. No bond strap should be more than four inches in length.

Shielding is one of the most effective methods of suppressing radio noise. The primary object in shielding is to electrically "bottle up" the radiofrequency noise energy. In practical applications, this means that the radio noise energy must be kept flowing along the inner surface of the shield. The use of good shielding is particularly effective in situations where filters cannot be used and are not particularly effective when they are used. A good example of this is where radio noise energy radiates from a radio noise source and the radiated energy is picked up by the various circuits that eventually connect to the receiver input circuits. It is obvious that it would be impractical to filter a number of leads or units that are influenced by the radio noise energy; hence, the application of effective shielding at the noise source itself is advisable for it will eliminate the radiated portion of the radio noise energy by confining it within the shield at its source.

Radio interference as radiated or conducted from a source may be of a single frequency or may cover an extended band of frequencies. When bonding, shielding, or isolation of the source proves ineffective as a means of reducing radio interference, it becomes necessary to employ filters to accomplish this reduction. A filter is defined as "a selective network which transmits freely electric waves having frequencies within one or more frequency bands and which attenuates substantially electric waves having other frequencies." The size of a filter may vary widely depending on the voltage and current requirements as well as the degree of attenuation desired. Filters are usually incorporated in equipment known to generate radio interference, but these filters are often inadequate, and in many cases it is necessary to add filters external to these equipments. This is especially true if the source of interference is coupling interference to paths of entry to a receiver other than the power line.

The types of filters used in the reduction of radio interference vary with the application, but each of the general filter types may be found to be particularly adaptable to some specific situation. Most of the electrical devices connected to power lines have features required for their operation, which are conducive to the generation of radio interference. The interference generated by these devices, unless properly attenuated, is impressed upon the power lines and conducted to the receivers. It may also be conducted into the receivers by inductive coupling to other wiring associated with the receivers. This interference, unless attenuated by means of filters, is then transmitted along these power lines, entering the receivers at the power line input; or this interference may be radiated somewhere along the power lines and enter the receiver by means of the antenna system.

Filters are of four kinds and are defined as follows:

Low-pass filter, which introduces negligible attenuation at all frequencies below a certain frequency, called the cutoff frequency, and relatively high attenuation at all higher frequencies.

High-pass filter, which introduces negligible attenuation at all frequencies above a certain frequency, called

the cutoff frequency, and relatively high attenuation at all lower frequencies.

Band-pass filter, which introduces negligible attenuation at all frequencies within the range between two frequencies, and relatively high attenuation at all other frequencies.

Band-elimination filter, which introduces negligible attenuation at all frequencies outside a certain range, and relatively high attenuation at all frequencies inside that range. (NOTE: For information that covers the theory of operation of these filters refer to NavPers 10087, *Basic Electronics*.)

The normal characteristics of a filter are obtained only when the filter is properly terminated in its characteristic impedance.

A wave trap is a filter or network especially designed to reject certain frequencies, or bands of frequencies. Networks of this type may be installed at the antenna of the transmitter or receiver in order to attenuate frequencies outside of the assigned frequency range of the equipment. All such networks must have low insertion, loss, or attenuation, for the pass frequencies. In the design and construction of wave traps, the insertion loss is usually below 2 db.

There are two basic circuit configurations for filter networks, the pi-section and the T-section. Each may be broken down into half sections which have an inverted L-shape and are known as L-section filters. If a number of pi- or T-sections are connected in series to form a filter, the resultant network is called a ladder network. Any of the above circuit configurations may be used for radio interference elimination.

In general, the use of simple capacitor filters is to be preferred over that of the more complicated network filters in cases where this type of filter provides the required degree of radio interference attenuation. In this method, the radio noise energy passes through the capacitor to ground and then back to its source. This short-circuiting effect is due to the fact that the capacitor offers a very low impedance path across the noise source terminals.

A given capacitor is effective in bypassing only a limited range of radio interference frequencies because

of its internal inductance and the inductance of the connecting leads. The inductance of the capacitor depends upon its capacity, the material of which it is fabricated, and the length of the connecting leads. The capacitor leads are the major contributors to the inductance of capacitors. For these reasons, small mica capacitors with short leads are more effective as filters at high frequencies than large paper capacitors with normally long leads. Electrolytic capacitors should never be used as filters because of the danger of dielectric breakdown.

The popularity of the capacitor type filter is due to the fact that the current used for operation of the radio noise source does not have to pass through the filter. The only energy passing through the filter is the radio noise energy. The most important limiting factor in the choice of a capacitor-type filter is the breakdown voltage rating of the capacitor. It must be well above the voltage used to operate the source of radio noise to be filtered. For example, where a 24-volt source of noise is to be bypassed with a capacitor, the working voltage of the capacitor should be at least 50 volts.

Definitions for Aircraft Electronics

Oftentimes it is difficult to understand just what someone has in mind when he is referring to electronic equipment. Terms such as component, part, subassembly, assembly, unit, group, set, system, accessory, and attachment are used to describe this equipment. One person will use one of these terms when referring to a particular equipment and another will use another of the terms to refer to the same equipment. This results in confusion and misunderstanding.

BuAer Instruction 10550.14A sets forth standard definitions for electronic equipment. The information that follows defines the various terms and gives examples of their application. (See fig. 14-18.)

An accessory is a part, subassembly, or assembly designed for use in conjunction with or to supplement another assembly, or a unit or set, contributing to the effectiveness thereof without extending or varying the basic function of the assembly or set. An accessory may be used for testing, adjusting, or calibrating purposes.

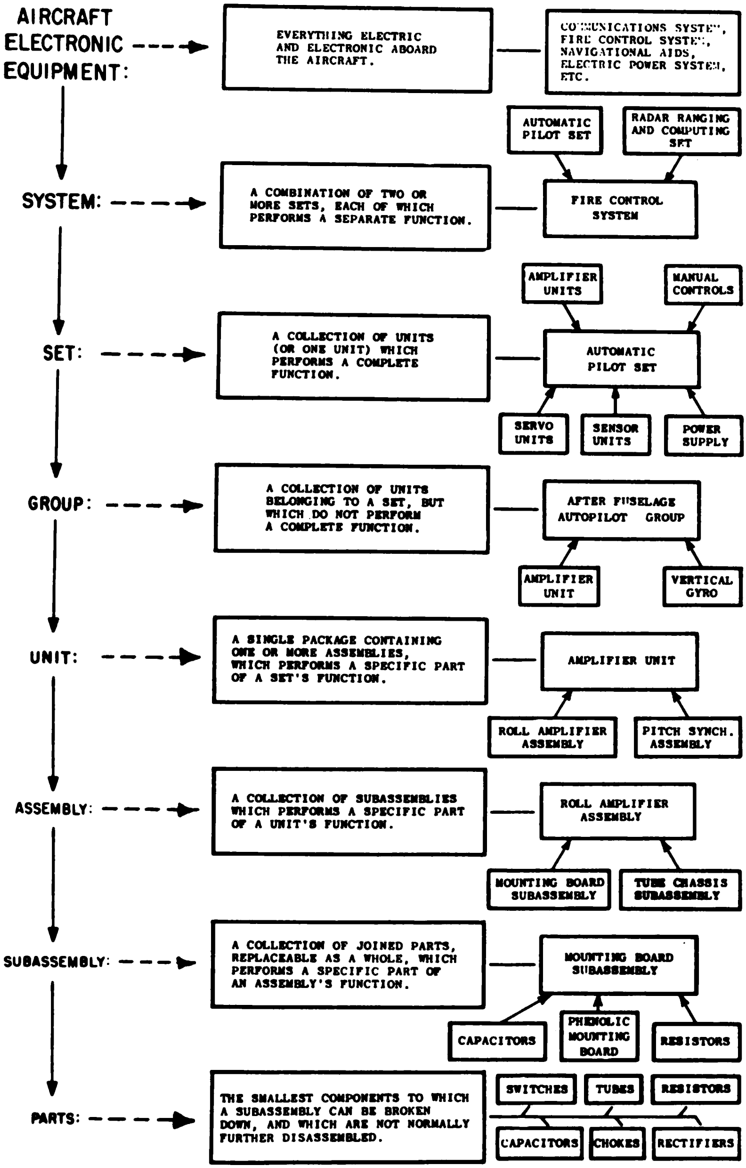


Figure 14-18.—Definitions for aircraft electronics.

An attachment is defined as a part, subassembly, or assembly designed for use in conjunction with another assembly or a unit or set, contributing to the effectiveness thereof by extending or varying the basic function of the assembly, unit, or set.

MAINTENANCE TECHNIQUES

Brush Contouring Device

In order to receive optimum performance from rotating machines that utilize brushes, it is important that the brushes make proper contact with the commutator or sliprings. Inspections of generators and motors have revealed that faulty operation is caused in many cases because the brushes do not properly fit the commutator or sliprings. This could be caused by the brushes having not been properly run-in when they were installed.

The discussion that follows describes a brush contouring device that can be easily constructed at most electric shops. If properly used, it will insure proper brush seating and also save much time. Should you decide to construct one of these devices you may not want to follow the exact procedure that follows. However, the information that is given should prove helpful as a guide.

Figure 14-19 shows the disassembled parts that are needed for constructing the device and figure 14-20 shows an assembled view.

The following materials are needed (refer to fig. 14-19):

1. One piece of laminated plastic (A) 4 x 6 x 1/2 inch.
2. One brass disk (B), one inch thick, drilled in center to receive bolt for mounting.
3. One piece of angle aluminum (C) 1 x 1 x 2-1/2 inches.
4. One piece of 1/8-inch plastic (D) 2-1/2 x 3 inches.
5. One bolt (E) for mounting disk and two instrument mounting screws. One of these screws to be fitted with a wingnut.

Part (B) must be turned on a lathe since its diameter is critical. This part must be the same diameter as the commutator or slipring for which the brush is being fitted.

The following steps should be used when contouring brushes:

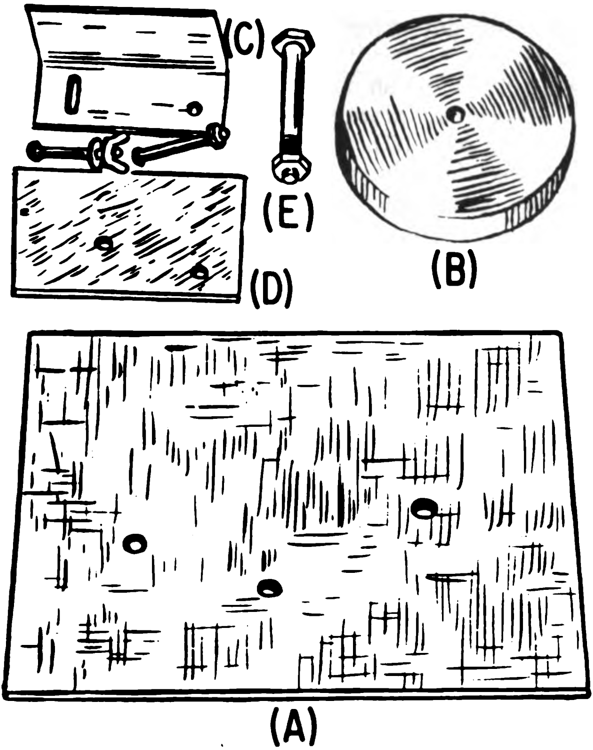


Figure 14-19.—Parts required for contouring device.

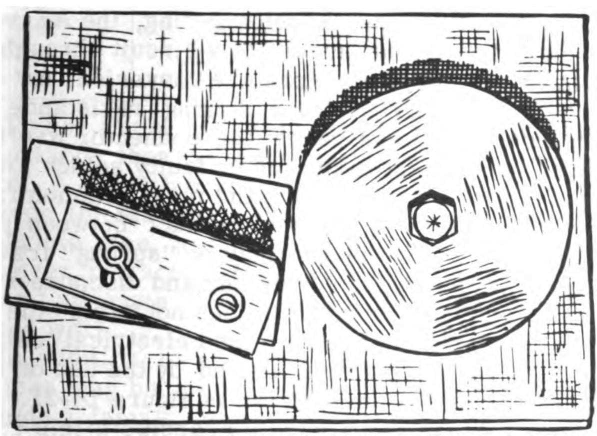


Figure 14-20.—Assembly of contouring device.

1. Loosen the adjusting bolt in the elongated slot in part (C).

2. Using an old brush removed from the generator, motor, or electrical starter, place brush against the angle aluminum, part (C), moving angle until brush contacts brass disk throughout its contoured surface. Lock part (C) with wingnut. *Caution:* Use only properly seated brushes for step 2.

3. One person then holds a strip of very fine sandpaper, 1 inch wide, on outer diameter of brass disk, and pulls the ends alternately back and forth, keeping sandpaper taut. The other person holds a new brush against part (C) and pushes lightly against the sandpaper until the proper contour is formed on the brush end. NOTE: Be careful to keep brush tight against part (C) during contouring.

By contouring brushes with this device instead of in the generator, all carbon, dust, grit and so forth are kept out of the generator. Moreover, the brush surface will be contoured at the correct angle with respect to the longitudinal axis of the brush. With the device, less run-in time is required, there is less chance of generator failure due to brushes heating, and excessive commutator and slipring wear is eliminated.

Testing AN Connectors

In the course of normal troubleshooting, the AE very often has occasion to gain access to a circuit through an AN connector. These connectors are convenient for obtaining voltage checks, and for making resistance or continuity tests. In some cases, the connector itself is found to be faulty. Next to broken or faulty solder joints in the back of the connector pins, the most common fault of connectors is loss of internal contact between pins and receptacles. A receptacle may be "sprung" from a physical blow, or repeated connecting and disconnecting. When this occurs, the receptacle does not "grip" the pin with sufficient tension to maintain good electrical contact.

Corrective tension may be checked by the use of test devices similar to the ones shown in figure 14-21. Old ignition lead connectors are used for handles in this case, but any other suitable material may be used. Inserted

and secured within the phenolic handles are steel pins machined to the proper diameters shown in table 14-1. (Brass pins from spare connectors may be used, but they wear quickly.)

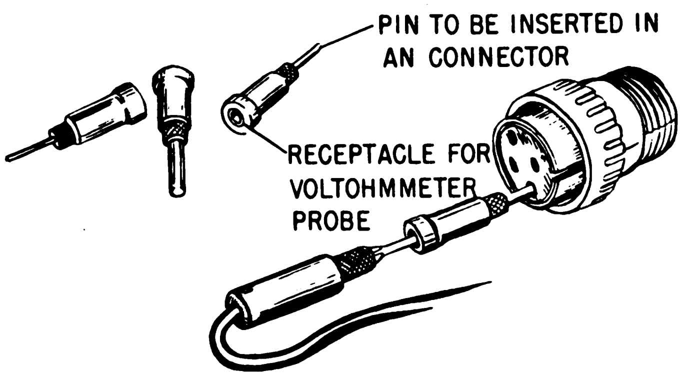


Figure 14-21.—AN connector and test devices.

Table 14-1.—Connector Pin Size and Separating Forces.

Connector sizes	Pin size ±0.0001	Force in pounds	
		Maximum	Minimum
16	0.0625 in.	3	1/4
12	0.094	5	1/2
8	0.142	10	3/4
4	0.225	15	1
0	0.357	20	2

To use a test pin, it is inserted to its full depth in a receptacle, then pulled straight out, with no side pressure. A defective receptacle is indicated by a lack of grip on the test pin. A spring scale, or weights of appropriate size, are used to make an accurate check. However, retracting-force requirements are quite broad, so that adequate "feel" may be developed, and thus speed up the work.

In addition to checking connective tension, the test devices may be used as adapters. Each test device may include a female receptacle in the end opposite the male testing pin. This receptacle is drilled to an inside

diameter to accommodate the standard voltohmmeter test probe. By selecting the test device adapter with the correct size pin, a secure test connection may be made to any size connector receptacle. The voltohmmeter probe may then be inserted into the drilled receptacle; thereby, it will not have to be held by hand in a receptacle too large for it, nor will it "spring" a receptacle that is too small.

Replacement of Parts

New designs and new techniques in the manufacture of electronic equipment require that some of the old standards be revised. Among these are methods of soldering special parts, such as transistors and crystal diodes. These semiconductors cannot safely withstand the heat that even the pencil type soldering irons must produce to melt the solder that connects them in a circuit, unless a heat shunt is used.

Another change that new design dictates is the method of soldering wires or parts to terminal posts or connectors. The discussion that follows sets forth the recommended soldering procedures as developed by the Navy Electronics Laboratory.

SOLDERING SEMICONDUCTORS.—Much new circuit design is based on the use of semiconductors. While some devices operate safely at high temperatures, the majority of transistors and crystal diodes in use are particularly sensitive to temperature.

In most cases, transistors are mounted in sockets. They should be removed from the sockets before any soldering of the socket terminals takes place. Some transistors and most crystal diodes in printed circuits are soldered directly in place. It is best, in these cases, to use a heat shunt, such as the one shown in figure 14-22. It should be clipped on the lead being soldered, between the joint and the transistor, diode, or resistor, to dissipate the excess heat. Other tools that may be used as heat shunts are medical hemostats and pointed nose pliers. (Hemostats may be obtained from the sick bay or hospital when they are no longer usable for surgical purposes. You will find them an invaluable addition to your tool box.)

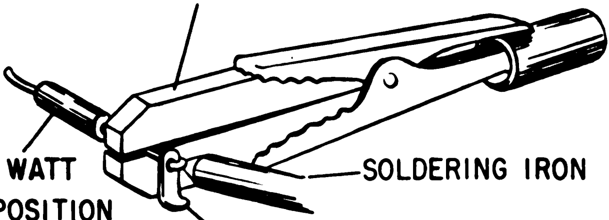


Figure 14-22.—Heat shunt.

STRENGTH OF SOLDERED CONNECTIONS.—The various radio and electronics handbooks emphasize the necessity of tightly wrapping wires around terminals before soldering. This practice is required by federal specifications, but efforts are now being made to revise the requirements in the light of recent investigations on solder strength.

The Navy Electronics Laboratory tested many standard capacitors and resistors soldered to terminals of various types. These were subjected to vibrations far in excess of those encountered in military ships, aircraft, and armored vehicles. Although the connections were deliberately made with no wrapping of wires around terminals, but instead with reliance for support placed in the soldered joint, there were no failures. (See fig. 14-23.) Similar tests, with equally encouraging results, have been conducted by a number of commercial electronics firms.

The following advantages are gained from using connections that depend on solder for strength: (1) ease of assembly; (2) ease of removal for test or replacement; (3) less chance of poor soldering (lack of solder in joints and/or rosin joints) since faulty soldering is more readily detected by visual or electrical inspection methods than when the wire is wrapped before soldering; (4) less heat required in soldering and unsoldering; and (5) less strain on parts since their leads do not get as much pulling and twisting as with the conventional wrapping technique.

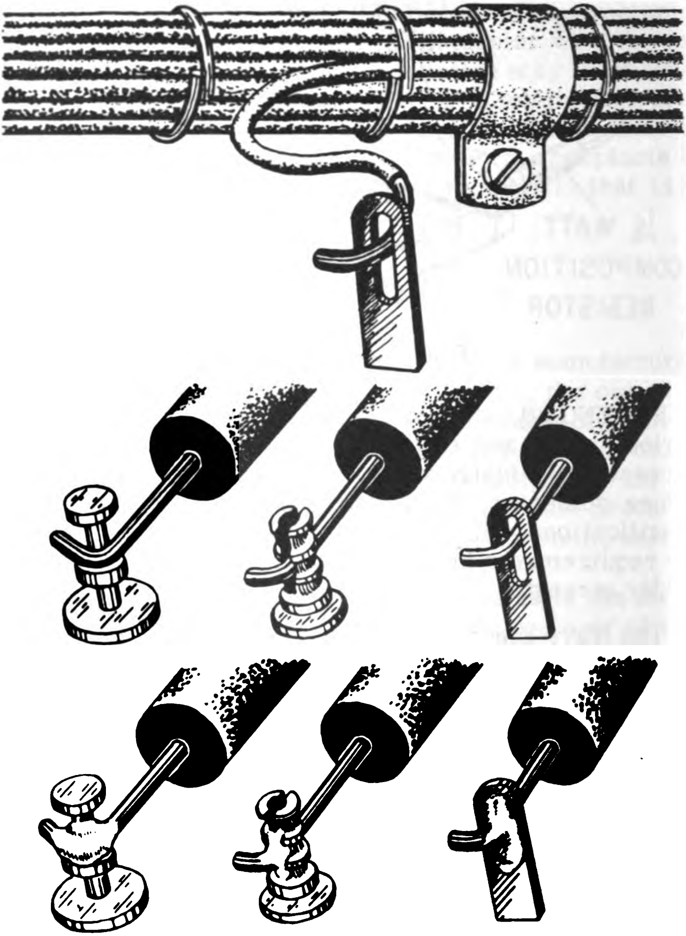


Figure 14-23.—Soldering method recommended by Navy Electronics Laboratory.

Recommendations have been made that federal specifications be revised to require that small parts be connected with no more than one-half turn of wire around the terminal, followed by a simple and neat soldering job.

TEMPERATURE OF SOLDERING IRONS.—All high quality irons operate in the temperature range of 500° to 600° F. Even the little 25-watt midget irons produce this

temperature. The important difference in iron sizes is not temperature, but the capacity of the iron to generate and maintain a satisfactory soldering temperature while giving up heat to the joint to be soldered. Naturally you would not try to solder a tin box with the 25-watt iron, but you would find that iron quite suitable for replacing a half-watt resistor in a printed circuit. Of course, a 150-watt iron would be satisfactory for the printed circuit, provided proper soldering techniques are used, since it gets no hotter than the 25-watt iron. The advantage of using the small iron for small work is that it is light and easy to handle and has a small tip that is easily inserted into close places.

Some irons have built-in thermostats. Others are provided with thermostatically controlled stands. These devices control the temperature of the soldering iron, but are a source of trouble. A well-designed iron is self-regulating by virtue of the fact that the resistance of its element increases with rising temperature, thus limiting the flow of current. For critical work, it is convenient to have a variable transformer for fine adjustment of heat, but for general purpose work, no temperature regulation is needed.

One type of iron is equipped with several different tips that range from 1/4 inch to 1/2 inch in size (diameter) and are of various shapes. This feature makes it adaptable to a variety of jobs. Unlike most tips which are held in place by setscrews, these tips are threaded and screw into the barrel. This feature provides excellent contact with the heating element, thus improving heat transfer efficiency. A pad of "antifreeze" compound is supplied with each iron. This compound is applied to the threads each time a tip is installed in the iron, thereby enabling the tip to be easily removed when another is to be inserted.

A special feature of this iron is the soldering pot that screws in like a tip and holds about a thimbleful of solder. It is useful for tinning the ends of large numbers of wires. Keep a jar of rosin-alcohol solution handy to apply flux to the wires just before dipping in the molten solder.

SOLDERING GUN.—Because it heats fast and cools fast, the soldering gun has gained great popularity in recent years. It is especially well adapted to maintenance and troubleshooting work where only a small part

of the technician's time is spent actually soldering, as a continually hot iron oxidizes rapidly and is difficult to keep clean.

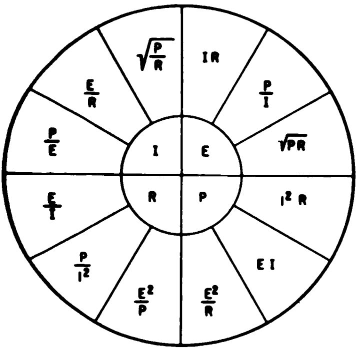
A transformer in the gun supplies about 1 volt at high current to a loop of copper that serves as the tip. It heats to soldering temperature in 3 to 5 seconds, but will heat to as high as 1,000° F. if left on longer than 30 seconds. Because it operates for short periods of time, very little oxidation is allowed to form; thus, it is one of the easiest soldering tools to keep well tinned. On the other hand, this tip is made of pure copper with no plating, so pitting can easily occur as a result of the dissolving action of the solder. Offsetting this disadvantage, however, is the low cost of replacement tips—about 13 cents.

If delicate wires or printed circuits are to be soldered with a gun, it should be remembered that overheating can easily occur. With practice, heat can be accurately controlled by pulsing the gun on and off with its trigger. For most jobs, even the LOW position of the trigger will overheat the tip after 10 seconds. The HIGH position is only for fast heating and for soldering to especially large terminals. Incidentally, it is permissible to use soldering guns as well as regular soldering irons on the 400-cycle supply. In the case of guns, the heating time will increase and the maximum temperature will be somewhat lower, but no harm will result to the gun, and satisfactory soldering temperatures can be obtained.

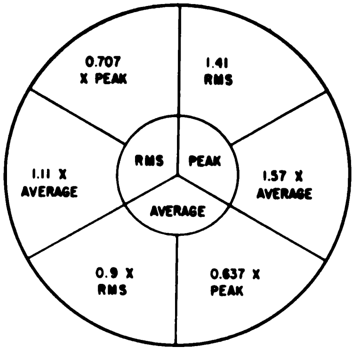
Electrical Relationships

Figure 14-24 shows formulas that can be used for determining electrical or associated relationships.

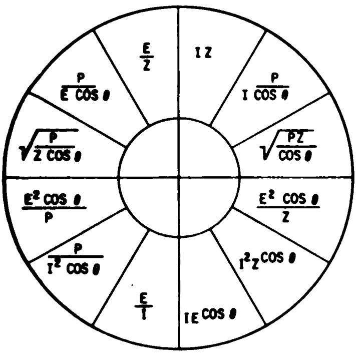
OHMS LAW FOR D-C CIRCUITS



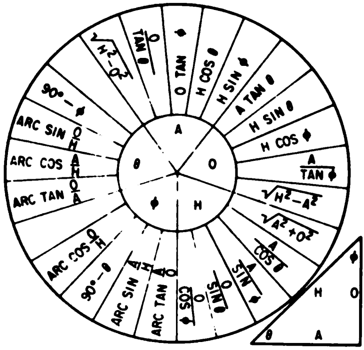
A-C VOLTAGE RELATIONS



OHMS LAW FOR A-C CIRCUITS



FUNCTIONS OF A RIGHT ANGLE



POWER FACTOR $\frac{EI\cos\theta}{EI}$

RATIO $\frac{\text{NAUTICAL MILE}}{\text{STATUTE MILE}} = \frac{7.60}{6.60}$

CIRCULAR MILS = SQ. MILS x 0.7854

ONE RADIAN = $\frac{360°}{2\pi}$ = 57.3°

RADIANS = DEGREES x 0.0175

SECONDS OF ARC = 206265 = $\frac{360° \times 60' \times 60''}{2\pi}$

MINUTES OF ARC = 3438 = $\frac{360° \times 60'}{2\pi}$

Figure 14-24.—Electrical or associated relationships.

QUIZ

1. In measuring resistance with a vacuum tube voltohmmeter the unknown resistance is placed in series with
   a. B-plus in the VTVM
   b. the meter circuit
   c. a known resistance
   d. the vacuum tube

2. The amplifier sections for the vertical and horizontal voltages in an oscilloscope are operated class
   a. A
   b. B
   c. C
   d. AB2

3. The main purpose of using a 100-watt soldering iron instead of a 25-watt soldering iron is
   a. to be able to heat a larger surface
   b. to heat a surface to a higher temperature
   c. to be able to use a smaller tip
   d. there is no definite advantage

4. Nearly all oscilloscopes use
   a. electromagnetic focusing
   b. electrostatic deflection
   c. electromagnetic deflection
   d. electrostatic current deflection

5. The waveform of the voltage applied to the vertical plates of an oscilloscope
   a. must be a sawtooth
   b. must be a sine wave
   c. can be of any shape
   d. must be a square wave

6. In figure 14-10 the frequency on the horizontal plates is known to be 400 cycles. The frequency on the vertical plates is
   a. 900 cycles
   b. 60 cycles
   c. 180 cycles
   d. 800 cycles

7. The operator is protected from residual capacitive shock after the high-voltage tester has been turned off by use of a
   a. bleeder resistor
   b. high-voltage capacitor discharge switch
   c. grounded third wire
   d. insulated shock mounts

8. In measuring an unknown resistance with the vacuum tube voltohmmeter in figure 14-13, the meter reads midscale. The unknown resistance is approximately
   a. equal to the known selected resistance
   b. ten times as great as the selected resistance
   c. one-tenth as great as the selected resistance
   d. one-half as great as the selected resistance

9. Control of beam intensity in a cathode-ray tube is accomplished by varying the negative voltage applied to the
   a. control grid
   b. cathode
   c. second anode
   d. first anode

10. The main characteristic of a vacuum tube voltmeter that is utilized in measuring voltage drops in a high impedance circuit is its
   a. good frequency response
   b. balanced bridge circuit function
   c. extreme accuracy
   d. high input impedance

11. Corona conduction is best controlled by
   a. bonding
   b. felt
   c. shielding
   d. isolation

12. The easiest and most practical method of obtaining radio noise suppression is
   a. isolation
   b. bonding
   c. filtering
   d. shielding

13. In order to keep carbon dust from collecting in the generator and still seat the brushes properly, you should
   a. order the proper brushes
   b. construct a simple contouring device
   c. use a special seating compound
   d. use a special liquid for cleaning

14. The second anode of an electron gun in a cathode-ray tube
   a. accelerates the electron
   b. focuses the beam
   c. cuts off the beam
   d. deflects the beam

15. The two sine waves in figure 14-8 that are applied to the cathode-ray tube are
   a. 180 degrees out of phase
   b. in phase
   c. 90 degrees out of phase
   d. 45 degrees out of phase
16. Zero ohms position for the meter needle in figure 14-16 corresponds to
   a. maximum positive voltage on *V2A*'s grid
   b. maximum negative voltage on *V2A*'s grid
   c. plate voltage of *V2A* being larger than plate voltage on *V2B*
   d. minimum voltage drop across *R*30
17. When using battery power for the high-voltage tester, a. c. is obtained by use of a
   a. cold cathode diode
   b. autotransformer
   c. rectifier
   d. vibrator
18. The rectifier output ripple frequency in the high-voltage tester is
   a. twice the power supply frequency times the number of phases
   b. the power supply frequency times the number of phases
   c. twice the number of phases times the power supply frequency
   d. equal to the power supply frequency
19. Electrolytic capacitors
   a. should never be used as filters because of the danger of dielectric breakdown
   b. should always be used for noise filtering because they have low inductance
   c. should be used where high-frequency noises are to be filtered
   d. should always be used for noise filtering because they have high inductance
20. The rectified output voltage of *V1A* (12AL5) in figure 14-13 is
   a. negative in respect to ground
   b. positive in respect to ground
   c. applied to the grid of *V2B*
   d. zero in respect to ground
21. A high voltage test is used most often to
   a. detect leakage through insulation
   b. check resistance of air gaps
   c. check breakdown voltages of insulators
   d. measure voltage necessary to flash over

22. With the sweep generator applying a deflection voltage to the horizontal plates and with no voltage applied to the vertical plates, the beam produces a
    a. vertical straight line
    b. horizontal straight line
    c. line at 45 degrees from the vertical axis
    d. circle
23. The first anode in a cathode-ray electron gun is operated
    a. negative with respect to cathode
    b. negative with respect to grid
    c. negative with respect to second anode
    d. positive with respect to second anode

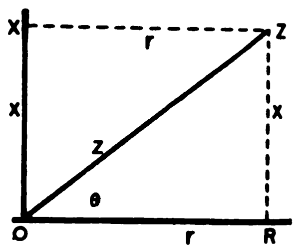
APPENDIX I

TRIGONOMETRIC FUNCTIONS

Several special relationships, called trigonometric functions, hold true in a right triangle. Electrical problems when reduced to a right triangle can be easily and quickly solved by use of tables based upon these functions.

In the diagram shown, θ is the angle *ZOR*, *OR* is the projection of *OZ* on the horizontal axis, *OX* is the projection of *OZ* on the vertical axis. The letters *r*, *x*, and *z* represent the lengths of *OR*, *OX*, and *ZO* respectively. There are, in all, six different ratios between the sides, *r*, *x*, and *z*. They are called trigonometric ratios or trigonometric functions.

Sine of θ (written $\sin\theta$) $= \frac{x}{z}$



Cosine of θ (written $\cos\theta$) $= \frac{r}{z}$

Tangent of θ (written $\tan\theta$) $= \frac{x}{r}$

Cotangent of θ (written $\cot\theta$) $= \frac{r}{x}$

Secant of θ (written $\sec\theta$) $= \frac{z}{r}$

Cosecant of θ (written $\csc\theta$) $= \frac{z}{x}$

The functions, $\sin\theta$, $\cos\theta$, and $\sec\theta$, are the reciprocals of $\cot\theta$, $\sec\theta$, and $\csc\theta$, respectively. Only the first three, $\sin\theta$, $\cos\theta$, and $\tan\theta$, are generally used.

Suppose that in the diagram, *OZ* has a unit length of 1 and is rotated in a counterclockwise direction beginning with angle θ at 0° value and continuing until it is 90°, then the functions will vary within the following limits:

$\sin\theta$ increases from 0 to 1.0
$\cos\theta$ decreases from 1.0 to 0
$\tan\theta$ increases from 0 to ∞
$\cot\theta$ decreases from ∞ to 0
$\sec\theta$ increases from 1.0 to ∞
$\csc\theta$ decreases from ∞ to 1.0.

When θ varies between the values of 90° and 180° (second quadrant), the projection r is negative and the functions which involve r become negative. Thus, cos θ and tan θ are negative in this quadrant. In the third quadrant, both r and x are negative. Therefore, sin θ and cos θ which involve only one or the other, are negative, while tan θ, which involves both r and x, is positive. In the fourth quadrant, r is positive, but x is still negative. For this reason, sin θ and tan θ are negative in the fourth quadrant, while cos θ is positive.

Variations in Value of Functions

Quadrant	Sin θ From	Sin θ To	Cos θ From	Cos θ To	Tan θ From	Tan θ To
I (0° - 90°)	0	1.0	1.0	0	0	∞
II (90° - 180°)	1.0	0	0	-1.0	$-\infty$	0
III (180° - 270°)	0	-1.0	-1.0	0	0	∞
IV (270° - 360°)	-1.0	0	0	1.0	$-\infty$	0

Trigonometric tables give functions up to 90° only. The following rules apply for functions of angles greater than 90°.

In quadrant II: θ = 90° + some angle which is designated α (alpha).

$$\sin(90° + \alpha) = \sin(90° - \alpha)$$
$$\cos(90° + \alpha) = -\cos(90° - \alpha)$$
$$\tan(90° + \alpha) = -\tan(90° - \alpha)$$

In quadrant III: $\theta = 180° + \alpha$

$$\sin(180° + \alpha) = -\sin\alpha$$
$$\cos(180° + \alpha) = -\cos\alpha$$
$$\tan(180° + \alpha) = \tan\alpha$$

In quadrant IV: $\theta = 270° + \alpha$

$$\sin(270° + \alpha) = -\sin(90° - \alpha)$$
$$\cos(270° + \alpha) = \cos(90° - \alpha)$$
$$\tan(270° + \alpha) = -\tan(90° - \alpha)$$

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
0	sin	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157
	cos	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999
	tan	0.0000	0.0017	0.0035	0.0052	0.0070	0.0087	0.0105	0.0122	0.0140	0.0157
1	sin	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332
	cos	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9996	0.9996	0.9995	0.9995
	tan	0.0175	0.0192	0.0209	0.0227	0.0244	0.0262	0.0279	0.0297	0.0314	0.0332
2	sin	0.0349	0.0366	0.0384	0.0401	0.0419	0.0436	0.0454	0.0471	0.0488	0.0506
	cos	0.9994	0.9993	0.9993	0.9992	0.9991	0.9990	0.9990	0.9989	0.9988	0.9987
	tan	0.0349	0.0367	0.0384	0.0402	0.0419	0.0437	0.0454	0.0472	0.0489	0.0507
3	sin	0.0523	0.0541	0.0558	0.0576	0.0593	0.0610	0.0628	0.0645	0.0663	0.0680
	cos	0.9986	0.9985	0.9984	0.9983	0.9982	0.9981	0.9980	0.9979	0.9978	0.9977
	tan	0.0524	0.0542	0.0559	0.0577	0.0594	0.0612	0.0629	0.0647	0.0664	0.0682
4	sin	0.0698	0.0715	0.0732	0.0750	0.0767	0.0785	0.0802	0.0819	0.0837	0.0854
	cos	0.9976	0.9974	0.9973	0.9972	0.9971	0.9969	0.9968	0.9966	0.9965	0.9963
	tan	0.0699	0.0717	0.0734	0.0752	0.0769	0.0787	0.0805	0.0822	0.0840	0.0857
5	sin	0.0872	0.0889	0.0906	0.0924	0.0941	0.0958	0.0976	0.0993	0.1011	0.1028
	cos	0.9962	0.9960	0.9959	0.9957	0.9956	0.9954	0.9952	0.9951	0.9949	0.9947
	tan	0.0875	0.0892	0.0910	0.0928	0.0945	0.0963	0.0981	0.0998	0.1016	0.1033
6	sin	0.1045	0.1063	0.1080	0.1097	0.1115	0.1132	0.1149	0.1167	0.1184	0.1201
	cos	0.9945	0.9943	0.9942	0.9940	0.9938	0.9936	0.9934	0.9932	0.9930	0.9928
	tan	0.1051	0.1069	0.1086	0.1104	0.1122	0.1139	0.1157	0.1175	0.1192	0.1210
7	sin	0.1219	0.1236	0.1253	0.1271	0.1288	0.1305	0.1323	0.1340	0.1357	0.1374
	cos	0.9925	0.9923	0.9921	0.9919	0.9917	0.9914	0.9912	0.9910	0.9907	0.9905
	tan	0.1228	0.1246	0.1263	0.1281	0.1299	0.1317	0.1334	0.1352	0.1370	0.1388
8	sin	0.1392	0.1409	0.1426	0.1444	0.1461	0.1478	0.1495	0.1513	0.1530	0.1547
	cos	0.9903	0.9900	0.9898	0.9895	0.9893	0.9890	0.9888	0.9885	0.9882	0.9880
	tan	0.1405	0.1423	0.1441	0.1459	0.1477	0.1495	0.1512	0.1530	0.1548	0.1566
9	sin	0.1564	0.1582	0.1599	0.1616	0.1633	0.1650	0.1668	0.1685	0.1702	0.1719
	cos	0.9877	0.9874	0.9871	0.9869	0.9866	0.9863	0.9860	0.9857	0.9854	0.9851
	tan	0.1584	0.1602	0.1620	0.1638	0.1655	0.1673	0.1691	0.1709	0.1727	0.1745
10	sin	0.1736	0.1754	0.1771	0.1788	0.1805	0.1822	0.1840	0.1857	0.1874	0.1891
	cos	0.9848	0.9845	0.9842	0.9839	0.9836	0.9833	0.9829	0.9826	0.9823	0.9820
	tan	0.1763	0.1781	0.1799	0.1817	0.1835	0.1853	0.1871	0.1890	0.1908	0.1926
11	sin	0.1908	0.1925	0.1942	0.1959	0.1977	0.1994	0.2011	0.2028	0.2045	0.2062
	cos	0.9816	0.9813	0.9810	0.9806	0.9803	0.9799	0.9796	0.9792	0.9789	0.9785
	tan	0.1944	0.1962	0.1980	0.1998	0.2016	0.2035	0.2053	0.2071	0.2089	0.2107
12	sin	0.2079	0.2096	0.2113	0.2130	0.2147	0.2164	0.2181	0.2198	0.2215	0.2232
	cos	0.9781	0.9778	0.9774	0.9770	0.9767	0.9763	0.9759	0.9755	0.9751	0.9748
	tan	0.2126	0.2144	0.2162	0.2180	0.2199	0.2217	0.2235	0.2254	0.2272	0.2290
13	sin	0.2250	0.2267	0.2284	0.2300	0.2318	0.2334	0.2351	0.2368	0.2385	0.2402
	cos	0.9744	0.9740	0.9736	0.9732	0.9728	0.9724	0.9720	0.9715	0.9711	0.9707
	tan	0.2309	0.2327	0.2345	0.2364	0.2382	0.2401	0.2419	0.2438	0.2456	0.2475
14	sin	0.2419	0.2436	0.2453	0.2470	0.2487	0.2504	0.2521	0.2538	0.2554	0.2571
	cos	0.9703	0.9699	0.9694	0.9690	0.9686	0.9681	0.9677	0.9673	0.9668	0.9664
	tan	0.2493	0.2512	0.2530	0.2549	0.2568	0.2586	0.2605	0.2623	0.2642	0.2661
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	42′	54′

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
15	sin	0.2588	0.2605	0.2622	0.2639	0.2656	0.2672	0.2689	0.2706	0.2723	0.2740
	cos	0.9659	0.9655	0.9650	0.9646	0.9641	0.9636	0.9632	0.9627	0.9622	0.9617
	tan	0.2679	0.2698	0.2717	0.2736	0.2754	0.2773	0.2792	0.2811	0.2830	0.2849
16	sin	0.2756	0.2773	0.2790	0.2807	0.2823	0.2840	0.2857	0.2874	0.2890	0.2907
	cos	0.9613	0.9608	0.9603	0.9598	0.9593	0.9588	0.9583	0.9578	0.9573	0.9568
	tan	0.2867	0.2886	0.2905	0.2924	0.2943	0.2962	0.2981	0.3000	0.3019	0.3038
17	sin	0.2924	0.2940	0.2957	0.2974	0.2990	0.3007	0.3024	0.3040	0.3057	0.3074
	cos	0.9563	0.9558	0.9553	0.9548	0.9542	0.9537	0.9532	0.9527	0.9521	0.9516
	tan	0.3057	0.3076	0.3096	0.3115	0.3134	0.3153	0.3172	0.3191	0.3211	0.3230
18	sin	0.3090	0.3107	0.3123	0.3140	0.3156	0.3173	0.3190	0.3206	0.3223	0.3239
	cos	0.9511	0.9505	0.9500	0.9494	0.9489	0.9483	0.9478	0.9472	0.9466	0.9461
	tan	0.3249	0.3269	0.3288	0.3307	0.3327	0.3346	0.3365	0.3385	0.3404	0.3424
19	sin	0.3256	0.3272	0.3289	0.3305	0.3322	0.3338	0.3355	0.3371	0.3387	0.3404
	cos	0.9455	0.9449	0.9444	0.9438	0.9432	0.9426	0.9421	0.9415	0.9409	0.9403
	tan	0.3443	0.3463	0.3482	0.3502	0.3522	0.3541	0.3561	0.3581	0.3600	0.3620
20	sin	0.3420	0.3437	0.3453	0.3469	0.3486	0.3502	0.3518	0.3535	0.3551	0.3567
	cos	0.9397	0.9391	0.9385	0.9379	0.9373	0.9367	0.9361	0.9354	0.9348	0.9342
	tan	0.3640	0.3659	0.3679	0.3699	0.3719	0.3739	0.3759	0.3779	0.3799	0.3819
21	sin	0.3584	0.3600	0.3616	0.3633	0.3649	0.3665	0.3681	0.3697	0.3714	0.3730
	cos	0.9336	0.9330	0.9323	0.9317	0.9311	0.9304	0.9298	0.9291	0.9285	0.9278
	tan	0.3839	0.3859	0.3879	0.3899	0.3919	0.3939	0.3959	0.3979	0.4000	0.4020
22	sin	0.3746	0.3762	0.3778	0.3795	0.3811	0.3827	0.3843	0.3859	0.3875	0.3891
	cos	0.9272	0.9265	0.9259	0.9252	0.9245	0.9239	0.9232	0.9225	0.9219	0.9212
	tan	0.4040	0.4061	0.4081	0.4101	0.4122	0.4142	0.4163	0.4183	0.4204	0.4224
23	sin	0.3907	0.3923	0.3939	0.3955	0.3971	0.3987	0.4003	0.4019	0.4035	0.4051
	cos	0.9205	0.9198	0.9191	0.9184	0.9178	0.9171	0.9164	0.9157	0.9150	0.9143
	tan	0.4245	0.4265	0.4286	0.4307	0.4327	0.4348	0.4369	0.4390	0.4411	0.4431
24	sin	0.4067	0.4083	0.4099	0.4115	0.4131	0.4147	0.4163	0.4179	0.4195	0.4210
	cos	0.9135	0.9128	0.9121	0.9114	0.9107	0.9100	0.9092	0.9085	0.9078	0.9070
	tan	0.4452	0.4473	0.4494	0.4515	0.4536	0.4557	0.4578	0.4599	0.4621	0.4642
25	sin	0.4226	0.4242	0.4258	0.4274	0.4289	0.4305	0.4321	0.4337	0.4352	0.4368
	cos	0.9063	0.9056	0.9048	0.9041	0.9033	0.9026	0.9018	0.9011	0.9003	0.8996
	tan	0.4663	0.4684	0.4706	0.4727	0.4748	0.4770	0.4791	0.4813	0.4834	0.4856
26	sin	0.4384	0.4399	0.4415	0.4431	0.4446	0.4462	0.4478	0.4493	0.4509	0.4524
	cos	0.8988	0.8980	0.8973	0.8965	0.8957	0.8949	0.8942	0.8934	0.8926	0.8918
	tan	0.4877	0.4899	0.4921	0.4942	0.4964	0.4986	0.5008	0.5029	0.5051	0.5073
27	sin	0.4540	0.4555	0.4571	0.4586	0.4602	0.4617	0.4633	0.4648	0.4664	0.4679
	cos	0.8910	0.8902	0.8894	0.8886	0.8878	0.8870	0.8862	0.8854	0.8846	0.8838
	tan	0.5095	0.5117	0.5139	0.5161	0.5184	0.5206	0.5228	0.5250	0.5272	0.5295
28	sin	0.4695	0.4710	0.4726	0.4741	0.4756	0.4772	0.4787	0.4802	0.4818	0.4833
	cos	0.8829	0.8821	0.8813	0.8805	0.8796	0.8788	0.8780	0.8771	0.8763	0.8755
	tan	0.5317	0.5340	0.5362	0.5384	0.5407	0.5430	0.5452	0.5475	0.5498	0.5520
29	sin	0.4848	0.4863	0.4879	0.4894	0.4909	0.4924	0.4939	0.4955	0.4970	0.4985
	cos	0.8746	0.8738	0.8729	0.8721	0.8712	0.8704	0.8695	0.8686	0.8678	0.8669
	tan	0.5543	0.5566	0.5589	0.5612	0.5635	0.5658	0.5681	0.5704	0.5727	0.5750
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
30	sin	0.5000	0.5015	0.5030	0.5045	0.5060	0.5075	0.5090	0.5105	0.5120	0.5135
	cos	0.8660	0.8652	0.8643	0.8634	0.8625	0.8616	0.8607	0.8599	0.8590	0.8581
	tan	0.5774	0.5797	0.5820	0.5844	0.5867	0.5890	0.5914	0.5938	0.5961	0.5985
31	sin	0.5150	0.5165	0.5180	0.5195	0.5210	0.5225	0.5240	0.5255	0.5270	0.5284
	cos	0.8572	0.8563	0.8554	0.8545	0.8536	0.8526	0.8517	0.8508	0.8499	0.8490
	tan	0.6009	0.6032	0.6056	0.6080	0.6104	0.6128	0.6152	0.6176	0.6200	0.6224
32	sin	0.5299	0.5314	0.5329	0.5344	0.5358	0.5373	0.5388	0.5402	0.5417	0.5432
	cos	0.8480	0.8471	0.8462	0.8453	0.8443	0.8434	0.8425	0.8415	0.8406	0.8396
	tan	0.6249	0.6273	0.6297	0.6322	0.6346	0.6371	0.6395	0.6420	0.6445	0.6469
33	sin	0.5446	0.5461	0.5476	0.5490	0.5505	0.5519	0.5534	0.5548	0.5563	0.5577
	cos	0.8387	0.8377	0.8368	0.8358	0.8348	0.8339	0.8329	0.8320	0.8310	0.8300
	tan	0.6494	0.6519	0.6544	0.6569	0.6594	0.6619	0.6644	0.6669	0.6694	0.6720
34	sin	0.5592	0.5606	0.5621	0.5635	0.5650	0.5664	0.5678	0.5693	0.5707	0.5721
	cos	0.8290	0.8281	0.8271	0.8261	0.8251	0.8241	0.8231	0.8221	0.8211	0.8202
	tan	0.6745	0.6771	0.6796	0.6822	0.6847	0.6873	0.6899	0.6924	0.6950	0.6976
35	sin	0.5736	0.5750	0.5764	0.5779	0.5793	0.5807	0.5821	0.5835	0.5850	0.5864
	cos	0.8192	0.8181	0.8171	0.8161	0.8151	0.8141	0.8131	0.8121	0.8111	0.8100
	tan	0.7002	0.7028	0.7054	0.7080	0.7107	0.7133	0.7159	0.7186	0.7212	0.7239
36	sin	0.5878	0.5892	0.5906	0.5920	0.5934	0.5948	0.5962	0.5976	0.5990	0.6004
	cos	0.8090	0.8080	0.8070	0.8059	0.8049	0.8039	0.8028	0.8018	0.8007	0.7997
	tan	0.7265	0.7292	0.7319	0.7346	0.7373	0.7400	0.7427	0.7454	0.7481	0.7508
37	sin	0.6018	0.6032	0.6046	0.6060	0.6074	0.6088	0.6101	0.6115	0.6129	0.6143
	cos	0.7986	0.7976	0.7965	0.7955	0.7944	0.7934	0.7923	0.7912	0.7902	0.7891
	tan	0.7536	0.7563	0.7590	0.7618	0.7646	0.7673	0.7701	0.7729	0.7757	0.7785
38	sin	0.6157	0.6170	0.6184	0.6198	0.6211	0.6225	0.6239	0.6252	0.6266	0.6280
	cos	0.7880	0.7869	0.7859	0.7848	0.7837	0.7826	0.7815	0.7804	0.7793	0.7782
	tan	0.7813	0.7841	0.7869	0.7898	0.7926	0.7954	0.7983	0.8012	0.8040	0.8069
39	sin	0.6293	0.6307	0.6320	0.6334	0.6347	0.6361	0.6374	0.6388	0.6401	0.6414
	cos	0.7771	0.7760	0.7749	0.7738	0.7727	0.7716	0.7705	0.7694	0.7683	0.7672
	tan	0.8098	0.8127	0.8156	0.8185	0.8214	0.8243	0.8273	0.8302	0.8332	0.8361
40	sin	0.6428	0.6441	0.6455	0.6468	0.6481	0.6494	0.6508	0.6521	0.6534	0.6547
	cos	0.7660	0.7649	0.7638	0.7627	0.7615	0.7604	0.7593	0.7581	0.7570	0.7559
	tan	0.8391	0.8421	0.8451	0.8481	0.8511	0.8541	0.8571	0.8601	0.8632	0.8662
41	sin	0.6561	0.6574	0.6587	0.6600	0.6613	0.6626	0.6639	0.6652	0.6665	0.6678
	cos	0.7547	0.7536	0.7524	0.7513	0.7501	0.7490	0.7478	0.7466	0.7455	0.7443
	tan	0.8693	0.8724	0.8754	0.8785	0.8816	0.8847	0.8878	0.8910	0.8941	0.8972
42	sin	0.6691	0.6704	0.6717	0.6730	0.6743	0.6756	0.6769	0.6782	0.6794	0.6807
	cos	0.7431	0.7420	0.7408	0.7396	0.7385	0.7373	0.7361	0.7349	0.7337	0.7325
	tan	0.9004	0.9036	0.9067	0.9099	0.9131	0.9163	0.9195	0.9228	0.9260	0.9293
43	sin	0.6820	0.6833	0.6845	0.6858	0.6871	0.6884	0.6896	0.6909	0.6921	0.6934
	cos	0.7314	0.7302	0.7290	0.7278	0.7266	0.7254	0.7242	0.7230	0.7218	0.7206
	tan	0.9325	0.9358	0.9391	0.9424	0.9457	0.9490	0.9523	0.9556	0.9590	0.9623
44	sin	0.6947	0.6959	0.6972	0.6984	0.6997	0.7009	0.7022	0.7034	0.7046	0.7059
	cos	0.7193	0.7181	0.7169	0.7157	0.7145	0.7133	0.7120	0.7108	0.7096	0.7083
	tan	0.9657	0.9691	0.9725	0.9759	0.9793	0.9827	0.9861	0.9896	0.9930	0.9965
Degs.	**Function**	**0′**	**6′**	**12′**	**18′**	**24′**	**30′**	**36′**	**42′**	**48′**	**54′**

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
45	sin	0.7071	0.7083	0.7096	0.7108	0.7120	0.7133	0.7145	0.7157	0.7169	0.7181
	cos	0.7071	0.7059	0.7046	0.7034	0.7022	0.7009	0.6997	0.6984	0.6972	0.6959
	tan	1.0000	1.0035	1.0070	1.0105	1.0141	1.0176	1.0212	1.0247	1.0283	1.0319
46	sin	0.7193	0.7206	0.7218	0.7230	0.7242	0.7254	0.7266	0.7278	0.7290	0.7302
	cos	0.6947	0.6934	0.6921	0.6909	0.6896	0.6884	0.6871	0.6858	0.6845	0.6833
	tan	1.0355	1.0392	1.0428	1.0464	1.0501	1.0538	1.0575	1.0612	1.0649	1.0686
47	sin	0.7314	0.7325	0.7337	0.7349	0.7361	0.7373	0.7385	0.7396	0.7408	0.7420
	cos	0.6820	0.6807	0.6794	0.6782	0.6769	0.6756	0.6743	0.6730	0.6717	0.6704
	tan	1.0724	1.0761	1.0799	1.0837	1.0875	1.0913	1.0951	1.0990	1.1028	1.1067
48	sin	0.7431	0.7443	0.7455	0.7466	0.7478	0.7490	0.7501	0.7513	0.7524	0.7536
	cos	0.6691	0.6678	0.6665	0.6652	0.6639	0.6626	0.6613	0.6600	0.6587	0.6574
	tan	1.1106	1.1145	1.1184	1.1224	1.1263	1.1303	1.1343	1.1383	1.1423	1.1463
49	sin	0.7547	0.7559	0.7570	0.7581	0.7593	0.7604	0.7615	0.7627	0.7638	0.7649
	cos	0.6561	0.6547	0.6534	0.6521	0.6508	0.6494	0.6481	0.6468	0.6455	0.6441
	tan	1.1504	1.1544	1.1585	1.1626	1.1667	1.1708	1.1750	1.1792	1.1833	1.1875
50	sin	0.7660	0.7672	0.7683	0.7694	0.7705	0.7716	0.7727	0.7738	0.7749	0.7760
	cos	0.6428	0.6414	0.6401	0.6388	0.6374	0.6361	0.6347	0.6334	0.6320	0.6307
	tan	1.1918	1.1960	1.2002	1.2045	1.2088	1.2131	1.2174	1.2218	1.2261	1.2305
51	sin	0.7771	0.7782	0.7793	0.7804	0.7815	0.7826	0.7837	0.7848	0.7859	0.7869
	cos	0.6293	0.6280	0.6266	0.6252	0.6239	0.6225	0.6211	0.6198	0.6184	0.6170
	tan	1.2349	1.2393	1.2437	1.2482	1.2527	1.2572	1.2617	1.2662	1.2708	1.2753
52	sin	0.7880	0.7891	0.7902	0.7912	0.7923	0.7934	0.7944	0.7955	0.7965	0.7976
	cos	0.6157	0.6143	0.6129	0.6115	0.6101	0.6088	0.6074	0.6060	0.6046	0.6032
	tan	1.2799	1.2846	1.2892	1.2938	1.2985	1.3032	1.3079	1.3127	1.3175	1.3222
53	sin	0.7986	0.7997	0.8007	0.8018	0.8028	0.8039	0.8049	0.8059	0.8070	0.8080
	cos	0.6018	0.6004	0.5990	0.5976	0.5962	0.5948	0.5934	0.5920	0.5906	0.5892
	tan	1.3270	1.3319	1.3367	1.3416	1.3465	1.3514	1.3564	1.3613	1.3663	1.3713
54	sin	0.8090	0.8100	0.8111	0.8121	0.8131	0.8141	0.8151	0.8161	0.8171	0.8181
	cos	0.5878	0.5864	0.5850	0.5835	0.5821	0.5807	0.5793	0.5779	0.5764	0.5750
	tan	1.3764	1.3814	1.3865	1.3916	1.3968	1.4019	1.4071	1.4124	1.4176	1.4229
55	sin	0.8192	0.8202	0.8211	0.8221	0.8231	0.8241	0.8251	0.8261	0.8271	0.8281
	cos	0.5736	0.5721	0.5707	0.5693	0.5678	0.5664	0.5650	0.5635	0.5621	0.5606
	tan	1.4281	1.4335	1.4388	1.4442	1.4496	1.4550	1.4605	1.4659	1.4715	1.4770
56	sin	0.8290	0.8300	0.8310	0.8320	0.8329	0.8339	0.8348	0.8358	0.8368	0.8377
	cos	0.5592	0.5577	0.5563	0.5548	0.5534	0.5519	0.5505	0.5490	0.5476	0.5461
	tan	1.4826	1.4882	1.4938	1.4994	1.5051	1.5108	1.5166	1.5224	1.5282	1.5340
57	sin	0.8387	0.8396	0.8406	0.8415	0.8425	0.8434	0.8443	0.8453	0.8462	0.8471
	cos	0.5446	0.5432	0.5417	0.5402	0.5388	0.5373	0.5358	0.5344	0.5329	0.5314
	tan	1.5399	1.5458	1.5517	1.5577	1.5637	1.5697	1.5757	1.5818	1.5880	1.5941
58	sin	0.8480	0.8490	0.8499	0.8508	0.8517	0.8526	0.8536	0.8545	0.8554	0.8563
	cos	0.5299	0.5284	0.5270	0.5255	0.5240	0.5225	0.5210	0.5195	0.5180	0.5165
	tan	1.6003	1.6066	1.6128	1.6191	1.6255	1.6319	1.6383	1.6447	1.6512	1.6577
59	sin	0.8572	0.8581	0.8590	0.8599	0.8607	0.8616	0.8625	0.8634	0.8643	0.8652
	cos	0.5150	0.5135	0.5120	0.5105	0.5090	0.5075	0.5060	0.5045	0.5030	0.5015
	tan	1.6643	1.6709	1.6775	1.6842	1.6909	1.6977	1.7045	1.7113	1.7182	1.7251
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	43′	54′

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
60	sin	0.8660	0.8669	0.8678	0.8686	0.8695	0.8704	0.8712	0.8721	0.8729	0.8738
	cos	0.5000	0.4985	0.4970	0.4955	0.4939	0.4924	0.4909	0.4894	0.4879	0.4863
	tan	1.7321	1.7391	1.7461	1.7532	1.7603	1.7675	1.7747	1.7820	1.7893	1.7966
61	sin	0.8746	0.8755	0.8763	0.8771	0.8780	0.8788	0.8796	0.8805	0.8813	0.8821
	cos	0.4848	0.4833	0.4818	0.4802	0.4787	0.4772	0.4756	0.4741	0.4726	0.4710
	tan	1.8040	1.8115	1.8190	1.8265	1.8341	1.8418	1.8495	1.8572	1.8650	1.8728
62	sin	0.8829	0.8838	0.8846	0.8854	0.8862	0.8870	0.8878	0.8886	0.8894	0.8902
	cos	0.4695	0.4679	0.4664	0.4648	0.4633	0.4617	0.4602	0.4586	0.4571	0.4555
	tan	1.8807	1.8887	1.8967	1.9047	1.9128	1.9210	1.9292	1.9375	1.9458	1.9542
63	sin	0.8910	0.8918	0.8926	0.8934	0.8942	0.8949	0.8957	0.8965	0.8973	0.8980
	cos	0.4540	0.4524	0.4509	0.4493	0.4478	0.4462	0.4446	0.4431	0.4415	0.4399
	tan	1.9626	1.9711	1.9797	1.9883	1.9970	2.0057	2.0145	2.0233	2.0323	2.0413
64	sin	0.8988	0.8996	0.9003	0.9011	0.9018	0.9026	0.9033	0.9041	0.9048	0.9056
	cos	0.4384	0.4368	0.4352	0.4337	0.4321	0.4305	0.4289	0.4274	0.4258	0.4242
	tan	2.0503	2.0594	2.0686	2.0778	2.0872	2.0965	2.1060	2.1155	2.1251	2.1348
65	sin	0.9063	0.9070	0.9078	0.9085	0.9092	0.9100	0.9107	0.9114	0.9121	0.9128
	cos	0.4226	0.4210	0.4195	0.4179	0.4163	0.4147	0.4131	0.4115	0.4099	0.4083
	tan	2.1445	2.1543	2.1642	2.1742	2.1842	2.1943	2.2045	2.2148	2.2251	2.2355
66	sin	0.9135	0.9143	0.9150	0.9157	0.9164	0.9171	0.9178	0.9184	0.9191	0.9198
	cos	0.4067	0.4051	0.4035	0.4019	0.4003	0.3987	0.3971	0.3955	0.3939	0.3923
	tan	2.2460	2.2566	2.2673	2.2781	2.2889	2.2998	2.3109	2.3220	2.3332	2.3445
67	sin	0.9205	0.9212	0.9219	0.9225	0.9232	0.9239	0.9245	0.9252	0.9259	0.9265
	cos	0.3907	0.3891	0.3875	0.3859	0.3843	0.3827	0.3811	0.3795	0.3778	0.3762
	tan	2.3559	2.3673	2.3789	2.3906	2.4023	2.4142	2.4262	2.4383	2.4504	2.4627
68	sin	0.9272	0.9278	0.9285	0.9291	0.9298	0.9304	0.9311	0.9317	0.9323	0.9330
	cos	0.3746	0.3730	0.3714	0.3697	0.3681	0.3665	0.3649	0.3633	0.3616	0.3600
	tan	2.4751	2.4876	2.5002	2.5129	2.5257	2.5386	2.5517	2.5649	2.5782	2.5916
69	sin	0.9336	0.9342	0.9348	0.9354	0.9361	0.9367	0.9373	0.9379	0.9385	0.9391
	cos	0.3584	0.3567	0.3551	0.3535	0.3518	0.3502	0.3486	0.3469	0.3453	0.3437
	tan	2.6051	2.6187	2.6325	2.6464	2.6605	2.6746	2.6889	2.7034	2.7179	2.7326
70	sin	0.9397	0.9403	0.9409	0.9415	0.9421	0.9426	0.9432	0.9438	0.9444	0.9449
	cos	0.3420	0.3404	0.3387	0.3371	0.3355	0.3338	0.3322	0.3305	0.3289	0.3272
	tan	2.7475	2.7625	2.7776	2.7929	2.8083	2.8239	2.8397	2.8556	2.8716	2.8878
71	sin	0.9455	0.9461	0.9466	0.9472	0.9478	0.9483	0.9489	0.9494	0.9500	0.9505
	cos	0.3256	0.3239	0.3223	0.3206	0.3190	0.3173	0.3156	0.3140	0.3123	0.3107
	tan	2.9042	2.9208	2.9375	2.9544	2.9714	2.9887	3.0061	3.0237	3.0415	3.0595
72	sin	0.9511	0.9516	0.9521	0.9527	0.9532	0.9537	0.9542	0.9548	0.9553	0.9558
	cos	0.3090	0.3074	0.3057	0.3040	0.3024	0.3007	0.2990	0.2974	0.2957	0.2940
	tan	3.0777	3.0961	3.1146	3.1334	3.1524	3.1716	3.1910	3.2106	3.2305	3.2506
73	sin	0.9563	0.9568	0.9573	0.9578	0.9583	0.9588	0.9593	0.9598	0.9603	0.9608
	cos	0.2924	0.2907	0.2890	0.2874	0.2857	0.2840	0.2823	0.2807	0.2790	0.2773
	tan	3.2709	3.2914	3.3122	3.3332	3.3544	3.3759	3.3977	3.4197	3.4420	3.4646
74	sin	0.9613	0.9617	0.9622	0.9627	0.9632	0.9636	0.9641	0.9646	0.9650	0.9655
	cos	0.2756	0.2740	0.2723	0.2706	0.2689	0.2672	0.2656	0.2639	0.2622	0.2605
	tan	3.4874	3.5105	3.5339	3.5576	3.5816	3.6059	3.6305	3.6554	3.6806	3.7062
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

Degs.	Function	0.0°	0.1°	0.2°	0.3°	0.4°	0.5°	0.6°	0.7°	0.8°	0.9°
75	sin	0.9659	0.9664	0.9668	0.9673	0.9677	0.9681	0.9686	0.9690	0.9694	0.9699
	cos	0.2588	0.2571	0.2554	0.2538	0.2521	0.2504	0.2487	0.2470	0.2453	0.2436
	tan	3.7321	3.7583	3.7848	3.8118	3.8391	3.8667	3.8947	3.9232	3.9520	3.9812
76	sin	0.9703	0.9707	0.9711	0.9715	0.9720	0.9724	0.9728	0.9732	0.9736	0.9740
	cos	0.2419	0.2402	0.2385	0.2368	0.2351	0.2334	0.2317	0.2300	0.2284	0.2267
	tan	4.0108	4.0408	4.0713	4.1022	4.1335	4.1653	4.1976	4.2303	4.2635	4.2972
77	sin	0.9744	0.9748	0.9751	0.9755	0.9759	0.9763	0.9767	0.9770	0.9774	0.9778
	cos	0.2250	0.2232	0.2215	0.2198	0.2181	0.2164	0.2147	0.2130	0.2113	0.2096
	tan	4.3315	4.3662	4.4015	4.4374	4.4737	4.5107	4.5483	4.5864	4.6252	4.6646
78	sin	0.9781	0.9785	0.9789	0.9792	0.9796	0.9799	0.9803	0.9806	0.9810	0.9813
	cos	0.2079	0.2062	0.2045	0.2028	0.2011	0.1994	0.1977	0.1959	0.1942	0.1925
	tan	4.7046	4.7453	4.7867	4.8288	4.8716	4.9152	4.9594	5.0045	5.0504	5.0970
79	sin	0.9816	0.9820	0.9823	0.9826	0.9829	0.9833	0.9836	0.9839	0.9842	0.9845
	cos	0.1908	0.1891	0.1874	0.1857	0.1840	0.1822	0.1805	0.1788	0.1771	0.1754
	tan	5.1446	5.1929	5.2422	5.2924	5.3435	5.3955	5.4486	5.5026	5.5578	5.6140
80	sin	0.9848	0.9851	0.9854	0.9857	0.9860	0.9863	0.9866	0.9869	0.9871	0.9874
	cos	0.1736	0.1719	0.1702	0.1685	0.1668	0.1650	0.1633	0.1616	0.1599	0.1582
	tan	5.6713	5.7297	5.7894	5.8502	5.9124	5.9758	6.0405	6.1066	6.1742	6.2432
81	sin	0.9877	0.9880	0.9882	0.9885	0.9888	0.9890	0.9893	0.9895	0.9898	0.9900
	cos	0.1564	0.1547	0.1530	0.1513	0.1495	0.1478	0.1461	0.1444	0.1426	0.1409
	tan	6.3138	6.3859	6.4596	6.5350	6.6122	6.6912	6.7720	6.8548	6.9395	7.0264
82	sin	0.9903	0.9905	0.9907	0.9910	0.9912	0.9914	0.9917	0.9919	0.9921	0.9923
	cos	0.1392	0.1374	0.1357	0.1340	0.1323	0.1305	0.1288	0.1271	0.1253	0.1236
	tan	7.1154	7.2066	7.3002	7.3962	7.4947	7.5958	7.6996	7.8062	7.9158	8.0285
83	sin	0.9925	0.9928	0.9930	0.9932	0.9934	0.9936	0.9938	0.9940	0.9942	0.9943
	cos	0.1219	0.1201	0.1184	0.1167	0.1149	0.1132	0.1115	0.1097	0.1080	0.1063
	tan	8.1443	8.2636	8.3863	8.5126	8.6427	8.7769	8.9152	9.0579	9.2052	9.3572
84	sin	0.9945	0.9947	0.9949	0.9951	0.9952	0.9954	0.9956	0.9957	0.9959	0.9960
	cos	0.1045	0.1028	0.1011	0.0993	0.0976	0.0958	0.0941	0.0924	0.0906	0.0889
	tan	9.5144	9.6768	9.8448	10.02	10.20	10.39	10.58	10.78	10.99	11.20
85	sin	0.9962	0.9963	0.9965	0.9966	0.9968	0.9969	0.9971	0.9972	0.9973	0.9974
	cos	0.0872	0.0854	0.0837	0.0819	0.0802	0.0785	0.0767	0.0750	0.0732	0.0715
	tan	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95
86	sin	0.9976	0.9977	0.9978	0.9979	0.9980	0.9981	0.9982	0.9983	0.9984	0.9985
	cos	0.0698	0.0680	0.0663	0.0645	0.0628	0.0610	0.0593	0.0576	0.0558	0.0541
	tan	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46
87	sin	0.9986	0.9987	0.9988	0.9989	0.9990	0.9990	0.9991	0.9992	0.9993	0.9993
	cos	0.0523	0.0506	0.0488	0.0471	0.0454	0.0436	0.0419	0.0401	0.0384	0.0366
	tan	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27
88	sin	0.9994	0.9995	0.9995	0.9996	0.9996	0.9997	0.9997	0.9997	0.9998	0.9998
	cos	0.0349	0.0332	0.0314	0.0297	0.0279	0.0262	0.0244	0.0227	0.0209	0.0192
	tan	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08
89	sin	0.9998	0.9999	0.9999	0.9999	0.9999	1.000	1.000	1.000	1.000	1.000
	cos	0.0175	0.0157	0.0140	0.0122	0.0105	0.0087	0.0070	0.0052	0.0035	0.0017
	tan	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	286.5	573.0
Degs.	Function	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′

APPENDIX II

ANSWERS TO QUIZZES

Chapter 1

DUTIES AND RESPONSIBILITIES

1. a.
2. b.
3. b.
4. d.
5. d.
6. c.
7. b.
8. b.
9. d.
10. c.
11. c.
12. a.
13. a.
14. d.
15. a.
16. a.

Chapter 2

SUPPLY AND PUBLICATIONS

1. a.
2. a.
3. a.
4. b.
5. d.
6. b.
7. d.
8. b.
9. c.
10. c.
11. d.
12. c.
13. a.
14. b.
15. a.
16. d.
17. a.
18. a.
19. c.
20. d.

Chapter 3

ADVANCED ALTERNATING-CURRENT THEORY

1. d.
2. c.
3. a.
4. b.
5. d.
6. c.
7. a.
8. d.
9. b.
10. a.
11. c.
12. c.
13. a.
14. c.
15. d.
16. d.
17. d.
18. b.
19. d.
20. c.

Chapter 4

ADVANCED ALTERNATING-CURRENT THEORY -- CONTINUED

1. b.
2. c.
3. d.
4. d.
5. a.
6. b.
7. b.
8. c.
9. a.
10. b.
11. b.
12. a.
13. a.
14. c.
15. b.
16. c.
17. c.
18. c.
19. d.
20. b.
21. a.
22. d.
23. c.
24. c.
25. b.

Chapter 5

MAGNETIC AMPLIFIERS

1. b.
2. d.
3. b.
4. d.
5. c.
6. c.
7. d.
8. b.
9. a.
10. a.
11. c.
12. c.
13. b.
14. c.
15. c.
16. b.
17. b.
18. a.
19. c.
20. b.
21. b.
22. a.
23. c.
24. c.
25. c.

Chapter 6

ALTERNATING-CURRENT MACHINERY

1. a.
2. c.
3. d.
4. c.
5. b.
6. d.
7. b.
8. b.
9. c.
10. d.
11. a.
12. d.
13. c.
14. d.
15. c.
16. b.
17. d.
18. b.
19. a.
20. c.
21. b.
22. a.
23. c.
24. c.
25. d.

Chapter 7

SERVOMECHANISMS

1. b.
2. b.
3. b.
4. a.
5. a.
6. b.
7. c.
8. c.
9. c.
10. c.
11. a.
12. b.
13. c.
14. a.
15. a.
16. d.
17. d.
18. d.
19. c.
20. c.
21. a.
22. d.

Chapter 8

INTRODUCTION TO TRANSISTORS

1. b.
2. b.
3. a.
4. c.
5. c.
6. d.
7. a.
8. a.
9. c.
10. d.
11. d.
12. b.
13. b.
14. d.
15. b.
16. b.
17. d.
18. a.
19. a.
20. c.

Chapter 9

AIRCRAFT COMPASS SYSTEMS

1. b.
2. a.
3. b.
4. c.
5. b.
6. c.
7. b.
8. b.
9. b.
10. b.
11. d.
12. c.
13. c.
14. d.
15. c.
16. d.

Chapter 10

AUTOMATIC FLIGHT CONTROL AND STABILIZATION SYSTEMS

1. d.
2. d.
3. c.
4. b.
5. a.
6. c.

7. c.
8. d.
9. c.
10. d.
11. b.
12. b.
13. c.
14. c.
15. a.
16. d.
17. b.

Chapter 11

PRESSURIZATION AND CABIN TEMPERATURE CONTROL

1. c.
2. d.
3. d.
4. c.
5. b.
6. a.
7. d.
8. b.
9. d.
10. a.
11. c.
12. c.
13. a.
14. d.
15. d.
16. c.
17. d.
18. a.
19. a.
20. c.

Chapter 12

PROPELLER SYNCHRONIZATION

1. b.
2. a.
3. c.
4. c.
5. c.
6. a.
7. c.
8. d.
9. d.
10. b.
11. c.
12. a.
13. b.
14. c.
15. a.

Chapter 13

D-C CONTROL, PROTECTIVE, AND WARNING DEVICES

1. a.
2. b.
3. b.
4. d.
5. a.
6. c.
7. a.
8. b.
9. a.
10. d.
11. d.
12. b.
13. b.
14. a.
15. c.
16. d.
17. c.
18. b.
19. b.
20. d.
21. b.
22. d.
23. b.
24. a.

Chapter 14

SPECIAL EQUIPMENT AND MAINTENANCE INFORMATION

1. c.
2. a.
3. a.
4. b.
5. c.
6. d.
7. b.
8. a.
9. a.
10. d.
11. a.
12. a.
13. b.
14. a.
15. b.
16. a.
17. d.
18. a.
19. a.
20. b.
21. a.
22. b.
23. c.

APPENDIX III

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION ELECTRICIAN'S MATES (AE)

(Extracted from NavPers 18068 (Revised) thru Change 12.)

RATING CODE NO. 6800

Professional Requirements

General Service Rating

Scope

Aviation Electrician's Mates maintain, adjust, test, repair, and replace all aircraft electrical and electronic power generating and converting, lighting, control, and indicating systems and components. Inspect, maintain, and install all aircraft electrical wiring. Maintain, adjust, test, and replace aircraft flight and engine instrument systems.

Emergency Service Ratings

AVIATION ELECTRICIAN'S MATES M (Electricians), Rating Code No. 6801 . . . . AEM

Maintain, adjust, test, repair, and replace all aircraft electrical power, lighting, control, and noninstrument indicating and warning systems and their components.

AVIATION ELECTRICIAN'S MATES I (Instrument Repairmen), Rating Code No. 6802 . . . . AEI

Maintain, adjust, test, and make authorized repairs to aircraft electronic, electrical, mechanical, and vacuum instrument systems and instrument-type warning systems and components.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classifications, NavPers 15105 (Revised), codes AE-7100 to AE-7199.

Qualification for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
100 PRACTICAL FACTORS			
101 OPERATIONAL			
1. Demonstrate method of resuscitating a man unconscious from electrical shock and of treating for electrical burns	3	3	3
2. Observe applicable safety precautions while working in or about aircraft and those prescribed for shop and line electrical maintenance	3	3	3
3. Operate Ground Electric Power Units required in the service and maintenance of aircraft	3	3	3
4. Perform operational test of aircraft electrical systems, including such flight tests as required by own activity	2	2	-
5. Perform operational test of aircraft instrument systems including such flight tests as required by own activity	2	-	2
102 MAINTENANCE AND/OR REPAIR			
1. Demonstrate safe and proper use and care of hand and power tools common to the rating	3	3	3
2. Detect, localize, and correct faults in electric lighting and power circuits, using a multimeter in testing for continuity, short circuits, and grounds	3	3	-
3. Read and work from schematic wiring diagrams in the maintenance and installation of aviation electrical circuits.	3	3	3
4. Identify characteristics of resistors and capacitors by the RMA code	3	3	3
5. Fabricate all types of cables used in aircraft electrical circuits, employing proper soldering and insulating techniques	3	3	3
6. Use handbook of maintenance instructions required in the maintenance of aviation electrical and instrument equipment	3	3	3
7. Demonstrate safe and proper use of general test equipment furnished own unit . .	3	3	3
8. Check and replace circuit breakers, fuses, and bonding wires	3	3	3
9. Remove and install aircraft power generating equipment, voltage regulators, and system protective devices.	3	3	-

Qualifications for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
102 MAINTENANCE AND/OR REPAIR--Continued			
10. Check condition of aircraft batteries; maintain, replace, and test them for proper charge	3	3	-
11. Disconnect and connect associated wiring to air frame and engine accessories. . . .	3	3	3
12. Install and test electrical wiring on Quick Engine Change Units	3	3	-
13. Replace and compensate electric remote indicating and magnetic compasses	3	-	3
14. Perform preventive maintenance, including external cleaning, lubricating, checking, replacing, and making minor adjustments to mechanical, electrical, and vacuum instruments	3	-	3
15. Perform preventive maintenance of aircraft electric wiring installation including wire, insulating materials, clamps, terminal strips, and connectors	3	3	-
16. Perform preventive maintenance on automatic pilot equipment	2	-	2
17. Make performance tests, including bench checks and adjustment of aircraft power generators, inverters, regulating controls, and power system protective devices . . .	2	2	-
18. Maintain, test, and adjust electrical indicating systems, including warning systems	2	2	2
19. Demonstrate safe and proper use of special test equipment furnished own activity for maintenance of:			
a. Aviation electrical equipment	2	2	-
b. Aircraft engine and flight instruments	2	-	2
20. Perform insulation resistance tests on wiring, using a megger or appropriate high voltage insulation tester	2	2	2
21. Perform periodic checks on Ground Electric Power Units to insure proper electric output	2	2	-
22. Perform electrical tests on components of ignition systems for proper operation	2	2	-
23. Maintain, adjust, and perform preflight checks on aircraft searchlights and their power supply systems	2	2	-
24. Maintain, test, replace, and adjust electric portions of aircraft electric-hydraulic systems	2	2	-
25. Test, adjust, calibrate, and make authorized repairs to aircraft instruments. . . .	1	-	2

Qualifications for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
102 MAINTENANCE AND/OR REPAIR--Continued			
26. Maintain and replace electric components of aircraft cabin pressurization, air-conditioning, and heater systems	1	1	-
27. Maintain and test aircraft propeller and engine electric/electronic control systems and their components	1	1	-
28. Make performance test including bench, preflight, and required in-flight adjustments to maintain proper operation of automatic pilot equipment	1	-	1
29. Test, adjust, and make authorized repairs to:			
a. Power, lighting, and noninstrument type indicating and warning systems	1	1	-
b. Electronic components used in instruments, automatic flight systems, and instrument type indicating and warning systems	1	-	1
30. Test, adjust, and make authorized repairs to components of aircraft electrical systems including servos, relays, protective devices, and all rotating electric equipment	1	1	-
31. Perform instrument repair, using required machines and special hand tools	-	-	1
32. Interpret wiring diagrams contained in handbooks of maintenance instructions in troubleshooting electrical systems	1	1	C
33. Analyze malfunctions and determine corrective action required on:			
a. Aircraft electrical systems	C	C	-
b. Aircraft instrument systems	C	-	C
103 ADMINISTRATIVE AND/OR CLERICAL			
1. Make required entries in aviation electrical shop maintenance records	3	3	3
2. Use NavAer Publications Index to locate, identify, and obtain technical publications	3	3	3
3. Complete electrical and/or instrument section of the Standard Aircraft Inventory Log	2	2	2
4. Determine part and stock numbers from available technical supply publications for obtaining replacement materials	2	2	2
5. Conduct on-the-job training and supervise personnel engaged in maintenance of:			

Qualifications for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
103 ADMINISTRATIVE AND/OR CLERICAL—Continued			
a. Aircraft electrical systems	1	1	-
b. Aircraft instrument systems	1	-	1
6. Furnish technical assistance in preparation of reports required by higher authority relating to electrical systems and/or equipment, including aircraft accident reports	C	C	C
7. Organize and administer personnel and facilities for maintenance of aviation electrical and/or instrument systems	C	C	C
8. Supervise the use, filing, and maintenance of publications and records; supervise preparation of reports required by own department	C	C	C
9. Supervise the requisition and inventory of, and account for allowed materials in accordance with current directives	C	C	C
10. Screen defective exchangeable electrical components and instruments, for feasibility of authorized local repair in lieu of exchange	C	C	C
200 EXAMINATION SUBJECTS			
201 OPERATIONAL			
1. Effects of electrical shock and methods of artificial respiration	3	3	3
2. Safety precautions to be observed in working in or near airplanes and on electrical equipment	3	3	3
202 MAINTENANCE AND/OR REPAIR			
1. Calculate current, voltage, power, and resistance in d-c series and parallel circuits containing not more than four elements	3	3	3
2. Given any two of the following values, solve for the remaining: (a) frequency, capacitance, and capacitive reactance; (b) frequency, inductance, and inductive reactance	3	3	3
3. Mathematical relationships between average, effective, and peak values of voltage and current in a-c circuits	3	3	3

Qualifications for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
202 MAINTENANCE AND/OR REPAIR—Continued			
4. Application of the laws of magnetism to simple d-c motors and generators	3	3	3
5. Operating principles and use of ohmmeters, voltmeters, and ammeters	3	3	3
6. Operating principles of and maintenance procedures for primary and secondary batteries	3	3	3
7. Identification of standard wiring code and wiring diagram symbols	3	3	3
8. Proper use of hand and small power tools and measuring instruments common to the rating	3	3	3
9. Types and characteristics of capacitors and resistors employed in aircraft electric and instrument equipment	3	3	3
10. Principles of hydraulics applicable to aircraft instruments	3	-	3
11. Operating principles of gyroscopes	3	-	3
12. Types and uses of aircraft a-c and d-c motors and generators	3	3	2
13. Types and uses of aircraft instruments . .	3	2	3
14. Principles and uses of synchros in aircraft control phase current and voltage transformers in aircraft electrical systems . .	2	2	3
15. Calculations involved in changing range of d-c meters by use of shunts and multiplier resistors	2	2	2
16. Principles of operation and applications of single phase current and voltage transformers in aircraft electrical systems . .	2	2	2
17. Effects of meter sensitivity in amplifier circuit voltage measurements	2	2	2
18. Principles of operation of thermocouples as used in aircraft fire detector, temperature indicating, and control circuits . . .	2	2	2
19. Determine values of: (a) voltage, current, or capacitance in both series and parallel capacitor circuits; (b) voltage, current, or inductance in a series inductor circuit	2	2	2
20. Solve problems involving relations between impedance voltages and line current in single-phase series a-c circuits	2	2	2
21. Principles of electromagnetic induction as employed in aircraft magnetos and engine ignition starting devices	2	2	-
22. Method of operation, characteristics, and functions of reverse current, over voltage,			

Qualifications for Advancement in Rating	AE	AEM	AEI
202 MAINTENANCE AND/OR REPAIR—Continued			
and feeder protective devices used in aircraft d-c power generating systems	2	2	-
23. Method of operation, characteristics, and maintenance techniques for finger type and carbon pile voltage regulators as used to control aircraft generators and inverters	2	2	-
24. Factors and calculations involved in selection of proper wire for aircraft electric circuits	2	2	-
25. Methods of speed regulation used in aircraft inverters	2	2	-
26. Voltage, current, and power relationship involved in three phase wye and delta a-c power distribution systems	2	2	1
27. Characteristics of triode, pentode, and tetrode vacuum tubes	2	2	1
28. Operating principles of half- and full-wave rectification	2	2	1
29. Operating principles of diode and dry-disk rectifiers	2	2	1
30. Methods of obtaining self and fixed bias for operation of vacuum tubes	2	2	1
31. Principles of operation of oscillator, amplifier, and signal discriminating circuits used in remote indicating compass and automatic pilot systems	2	2	1
32. Purpose and application of measuring instruments, including oscilloscopes, tube testers, a-c meters, vacuum tube voltmeters, and Wheatstone bridge	1	1	1
33. Relationship of the current, voltage, and impedance in LC circuits at, above, and below resonant frequency	1	1	1
34. Types, internal connections, and methods of testing armatures and field windings employed in aircraft a-c and d-c electrical rotating equipment.	1	1	1
35. Principles of operating single and polyphase a-c motors and generators	1	1	1
36. Characteristics of polyphase a-c generators and inverters in relation to load balance and power factor	1	1	1
37. Principle of operation of magnetic amplifiers	1	1	1
38. Method of operation, characteristics, and functions of under-frequency, overvoltage,			

Applicable Rates: AE, AEM, AEI

Qualifications for Advancement in Rating	Applicable Rates AE	AEM	AEI
202 MAINTENANCE AND/OR REPAIR—Continued			
and other protective devices used in a-c distribution systems	1	1	-
39. Method of operation of generator and inverter voltage and speed controls employing electronic and magnetic amplifiers . .	1	1	-
40. Purpose and application of instrument field and instrument special test equipment provided for squadron level maintenance	1	-	1
41. Application of band pass filters in aircraft instrument amplifiers	1	-	1
42. Methods of coupling used in electronic amplifiers: Transformer, resistive, capacitive, impedance, and direct	1	1	1
43. Types, application, phasing, and connecting of transformers in polyphase systems . .	1	1	C
44. Principles of signal phasing and followup as applied in electric automatic pilot servo systems and searchlight control systems	1	1	C
45. Factors causing and methods of locating, suppressing, and eliminating manmade radio noise interference.	C	C	C
46. Calculations for power factor correction and phase balancing in a-c power systems	C	C	C
203 ADMINISTRATIVE AND/OR CLERICAL			
1. Types of information found in NavAer Publications Index	3	3	3
2. Types of information contained in aeronautical technical publications, including operating handbooks, erection and maintenance manuals, allowance lists, parts catalogs, handbook of maintenance instructions, Aviation Circular Letters, Technical Notes, Technical Orders, Aircraft Service Changes, and bulletins pertinent to instrument and/or electrical systems.	2	2	2
3. General content and use of ASO Catalog . .	2	2	2
4. Safety precautions in chapter 18 of U. S. Navy Safety Precautions, OpNav 34P1. . .	1	1	1
5. Maintenance records, logs, and reports required of squadron maintenance department	C	C	C
6. Applications of military specifications in the installation and inspection of electrical equipment and wiring in naval aircraft . .	C	C	C

Qualifications for Advancement in Rating	Applicable Rates		
	AE	AEM	AEI
203 ADMINISTRATIVE AND/OR CLERICAL—Continued			
7. Use of applicable allowance lists, parts catalogs, and forms in the requisitioning and accounting for aviation electrical materials.	C	C	C
300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER			
Aviation Electrician's Mates advance to Warrant Aviation Electronics Technician and/or Limited Duty Officer, Aviation Electronics.			

Military Requirements

Scope

Military requirements are those generally applicable qualifications which all enlisted personnel are expected to demonstrate as a minimum for advancement to specific pay grades. They are applicable to all personnel at the specified pay grade except where indicated for men or women only.

For advancement, enlisted personnel in any pay grade need to demonstrate proficiency in the qualifications specified for the next higher pay grade and should maintain, and may be required to demonstrate, qualification for all lower pay grades.

Knowledges essential to performance of the practical factors, as well as those essential to the required examination subjects, will be subject to examination for advancement.

100 PRACTICAL FACTORS

	Applicable Pay Grade
101 OPERATIONAL	
1. Enter water feet first from height of 5 feet and swim 50 yards; float, scull, and tread water	E-2
2. Demonstrate techniques for preparing and using clothing and buoyant objects for staying afloat	E-2
3. Demonstrate how to put on and use inherently buoyant and CO_2-inflatable life jackets	E-2
4. Demonstrate how to control arterial and venous bleeding by compress, finger pressure, and tourniquet	E-2
5. Prepare and apply an improvised splint . . .	E-2

	Applicable Pay Grade
6. Administer artificial respiration by the back-pressure arm-lift method and back-pressure hip-lift method	E-2
7. Transport an injured person by: a. Fireman's lift. b. Tied-hands crawl.	E-2
8. Tie a bowline, becket bend, round turn and two half hitches, and square knot. (Men only.)	E-2
9. Locate an object by relative bearing and position angle measured in degrees. (Men only.)	E-2
10. Demonstrate ability to use ABC warfare protective equipment such as masks and clothing	E-2
11. Identify standard markers used to denote ABC warfare contamination	E-2
12. Adapt regular issue clothing for atomic and biological protection	E-2
13. Describe early symptoms of contamination of personnel by chemical warfare agents	E-3
14. Apply a battle dressing	E-3
15. Demonstrate how to apply immediate treatment for shock	E-3
16. Demonstrate techniques of swimming through oil, flames, and debris	E-3
17. Pronounce numbers and phonetic alphabet	E-3
18. Break out, man, test, and secure a sound-powered phone head set. (Men only.)	E-3
19. Demonstrate how to extinguish class A, B, and C fires. (Men only.)	E-3
20. Demonstrate how to use: (Men only.) a. Portable CO_2 extinguishers. b. Hoses, nozzles, and adapters. c. Safety lines and signals.	E-4

102 MAINTENANCE AND/OR REPAIR (Men only.)

1. Prepare aluminum, steel, and wood surfaces for painting	E-3
2. Paint aluminum, steel, and wood surfaces, using standard Navy techniques	E-3
3. Clean and stow paint brushes	E-3
4. Field-strip, clean, and assemble the service rifle	E-3
5. Field-strip, clean, and assemble the service pistol	E-4

103 ADMINISTRATIVE AND/OR CLERICAL

1. Prepare an indoctrination schedule for a new recruit reporting for duty	E-5
2. Select and organize appropriate subject matter and instruct by showing (demonstration) method	E-5

103 ADMINISTRATIVE AND/OR CLERICAL—Continued

	Applicable Pay Grade
3. Prepare a standard Navy letter	E-5
4. Prepare a detailed work assignment for men in your division	E-6
5. Teach a group, observing the following steps in developing the lesson: . . . . a. Setting the objectives. b. Presenting the subject matter. c. Providing trainee application through practical work and drill. d. Summarizing key points. e. Testing trainee achievement.	E-6
6. Prepare and administer a written test which includes the following types of questions: . . a. Essay. b. Multiple choice. c. True-false. d. Completion.	E-6
7. Use the following training aids and devices: a. Training film, slides, and transparencies. b. Charts, posters. c. Models and mock-ups. d. Demonstrators and trainers.	E-6
8. Prepare a preventive maintenance schedule for an item of machinery or equipment in your division, considering possible changes to ship employment schedule	E-7
9. Demonstrate ability to conduct instruction by each of the following methods, using subject matter appropriate to each method: . . . . . . a. Telling (lecture). b. Questions and discussion. c. Drill and practical work. d. Written study materials.	E-7
10. Plan and supervise on-the-job training program based on:. a. Level of trainees' knowledge and skill. b. Degree of skill to be developed. c. Available equipment and training aids. d. Qualifications for Advancement in Rating, NavPers 18068 (Revised).	E-7

104 MILITARY CONDUCT

1. Execute individual positions and facings used in close-order drill, with and without arms. (Men only.)	E-2
2. Execute individual positions and facings, without arms. (Women only.)	E-2
3. Fire the service rifle, observing safety precautions. (Men only.)	E-2
4. Relieve a watch, armed with rifle. (Men only.)	E-2

	Applicable Pay Grade
5. Stand sentry watch, observing general orders. (Men only.)	E-2
6. Stand a security watch. (Women only.)	E-2
7. Command a squad in close-order drill	E-4
8. Fire service pistol, observing safety precautions. (Men only.)	E-4
9. Relieve a watch, armed with pistol. (Men only.)	E-4

200 EXAMINATION SUBJECTS

201 OPERATIONAL

1. Procedures and safety precautions involved in performing tasks appropriate to the applicable pay grades listed under 100 Practical Factors.	
2. Individual action and precautions to be taken when exposed to atomic, biological, and chemical warfare attack ashore or afloat	E-2
3. Use and care of inherently buoyant and CO_2-inflatable life preservers. (Men only.)	E-2
4. Purpose and limitations of first aid	E-2
5. Symptoms of and first-aid treatment for simple and compound fractures.	E-2
6. Procedures to be followed in removing clothing at personnel decontamination stations	E-2
7. Rules of personal hygiene in relation to the following:	E-2
a. Body.	
b. Clothing.	
c. Bedding.	
d. Close living quarters.	
e. Dangers of self-treatment.	
8. Nomenclature of superstructure, decks, and parts of hull	E-2
9. Numbering system for decks and lettering and numbering system for compartments	E-2
10. Main purpose of following knots: (Men only.)	E-2
a. Bowline.	
b. Becket bend.	
c. Round turn and two half hitches.	
d. Square knot.	
11. Safety precautions to be observed in handling service rifle. (Men only.)	E-2
12. Symptoms of and immediate treatment for shock	E-3
13. Occasions and precautions for administering a morphine syrette	E-3
14. Classification of burns and symptoms of and first-aid treatment for each	E-3

15. Preparation for abandoning ship; best ways of going over the side; and type of clothing to be taken in abandoning ship in hot or cold climate. (Men only.) E-3
16. Use, care, and stowage of the following life float equipment: (Men only.) E-3
    a. Signal mirror.
    b. Day and night distress signal.
    c. Dye marker.
    d. First-aid kit.
    e. Rations.
    f. Tarpaulin.
17. Major types of and designating symbols for U. S. naval ships E-3
18. Major classes of and designating symbols for U. S. naval aircraft E-3
19. Material conditions of readiness of a ship. Meanings of W, X, Y, Z damage control markings. (Men only.) E-3
20. Types of guns installed aboard United States cruisers, destroyers, and naval aircraft . . . E-3
21. General purposes of the following types of naval ordnance: E-3
    a. Bombs.
    b. Rockets.
    c. Projectiles.
    d. Guided missiles.
    e. Depth charges.
    f. Torpedoes.
    g. Mines.
    h. Pyrotechnics.
22. Three classes of fires and their: E-3
    a. Causes.
    b. Prevention.
    c. Methods of handling.
23. Hazards of fire-produced smokes and fumes E-3
24. General safety precautions involved in working with or in vicintiy of: (Men only.) E-3
    a. Tank or closed compartment.
    b. Electrical and electronic equipment.
    c. Machinery and power tools.
    d. Fuels, paints, and solvents.
    e. Ammunition.
    f. Compressed gases.
    g. Life lines, ladders, and scaffolding.
    h. Heavy weights and moving equipment.
25. Safety precautions when working aloft or over the side. (Men only.) E-3
26. Safety precautions when embarked in small boats. E-3
27. Early symptoms of exposure to chemical warfare agents E-3

201 OPERATIONAL--Continued	Applicable Pay Grade
28. Sound signals for steam vessels during reduced visibility under way and at anchor. (Men only.)	E-4
29. Ship distress and break-down signals according to International Rules. (Men only.)	E-4
30. Whistle signals for meeting, crossing, and passing according to Inland Rules	E-4
31. United States buoyage system for marking channels and obstructions	E-4
32. Use of desalting kit and solar distilling equipment for obtaining drinking water; methods of catching and stowing rain water. (Men only.)	E-4
33. Safety precautions to be observed in handling service pistol. (Men only.)	E-4
34. Identify the semaphore positions for numbers and letters of the alphabet	E-5
35. Identify the International Morse Code for numbers and letters of the alphabet	E-5
36. Methods of decontaminating chemical, biological, and radioactive painted and unpainted surfaces. (Men only.)	E-7
37. Purpose and use of ABC warfare detector devices such as survey meters, dosimeters, and sampling kits	E-7

202 MAINTENANCE AND/OR REPAIR (Men only.)	
1. Methods of preparing wood, steel, and aluminum surfaces for painting	E-3
2. Uses of zinc chromate and red lead primers; exterior and interior paints	E-3
3. Methods of cleaning and stowing paint brushes	E-3

203 ADMINISTRATIVE AND/OR CLERICAL	
1. How and when to place personnel on report	E-4
2. Meaning and application of the following leadership principles:	E-4
a. Knowing the job to be done.	
b. Exhibiting and instilling pride in high standards of work.	
c. Seeking additional responsibility.	
d. Knowing your men and recognizing individual differences.	
e. Possessing sense of responsibility.	
f. Delegating authority but not responsibility.	
g. Keeping men informed.	
h. Being forehanded.	
i. Commanding and leading.	
3. Correct form for a standard Navy letter . . .	E-5

4. The purpose and relationship of the following in teaching a lesson: E-6
   a. Preparation.
   b. Presentation.
   c. Application.
   d. Test.
   e. Summary.
5. Standards to follow and errors to avoid in evaluating personnel for performance of duty marks E-6
6. Responsibilities of petty officers in on-the-job training programs regarding: E-6
   a. Training of individuals.
   b. Team training.
   c. Departmental training.
7. How and when to praise, censure, and warn E-7
8. Importance and effect of the following in planning and conducting instruction: E-7
   a. Objectives of the lesson.
   b. Characteristics of the subject or skill to be learned.
   c. Degrees of the skill required of trainees.
   d. Conditions, including time available, under which training must be conducted.
   e. Available equipment and training aids.
   f. Instructor-trainee relationships.

204 MILITARY CONDUCT

1. Eleven general orders for a sentry. (Men only.) E-2
2. When and to whom the individual hand and rifle salutes are rendered E-2
3. Military courtesies required of enlisted personnel in the following situations E-2
   a. During colors.
   b. Boarding or leaving a naval vessel.
   c. Crossing or being in the vicinity of the quarter-deck.
   d. When in military or civilian dress and the national ensign passes or national anthem is played.
   e. When passing, meeting, addressing, introducing, replying to, walking with, or riding with any commissioned officer attached to or serving with U. S. armed services.
4. Authority of and services rendered by military police patrols E-2
5. Identify officer grade insignia, and corps devices of the U. S. Navy E-2
6 Identify rates in pay grades E-1, E-2, and E-3 by sleeve insignia E-2

	Applicable Pay Grade
7. Identify rates of petty officers by sleeve insignia	E-2
8. Regulations for the correct wearing, markings, and exchanging of U. S. Navy enlisted uniforms for other than pay grade E-7	E-2
9. Principal occupational duties of general service ratings	E-2
10. Five types of discharge and reasons for each	E-2
11. Requirements and advantages of an honorable discharge	E-2
12. Identify the ribbons for the following medals:	E-3
a. Medal of Honor.	
b. Navy Cross.	
c. Good Conduct Medal.	
13. Names of parts of the Naval Establishment and the mission of each	E-3
14. Names, abbreviations, and broad responsibilities of the various bureaus of the Navy Department	E-3
15. Standard ship organization and the general responsibilities of each department	E-3
16. Purpose of watch, quarter, and station bill . .	E-3
17. Purpose of military discipline and punishment	E-3
18. Contents of the General Article (No. 134) of the Uniform Code of Military Justice and definition and significance of the following offenses:	E-3
a. Desertion.	
b. AWOL.	
c. Misuse of United States property.	
d. Insubordination.	
e. Fraudulent enlistment.	
f. Drunkenness or reckless driving.	
19. Types of courts martial and maximum punishments each may award	E-3
20. Punishments which the commanding officer may award	E-3
21. Meaning of basic pay, basic allowance for subsistence and quarters, and commuted rations	E-3
22. Types of hazardous duty entitling personnel to incentive pay. (Men only.)	E-3
23. Meaning and examples of rate and rating . .	E-3
24. General requirements for eligibility for advancement in rate or rating	E-3
25. Purpose and effect of performance of duty marks	E-3
26. Purpose of the following:	E-3
a. Service, fleet, and functional schools.	
b. Navy training courses.	
c. Enlisted correspondence courses.	
d. USAFI correspondence courses.	

	Applicable Pay Grade
e. USAFI self-study courses.	
f. Accreditation service of the information and education program.	
27. Opportunities for acquiring a naval commission in the following programs:	E-3
a. Officer Candidate School. (Men only.)	
b. Naval Reserve Officers Training Corps. (Men only.)	
c. Naval Aviation Cadet Program. (Men only.)	
d. Naval Academy. (Men only.)	
e. Reserve Officer Candidate. (Men only.)	
f. Reserve Officer Candidate (W). (Women only.)	
g. Officer Indoctrination (W). (Women only.)	
h. Naval Preparatory School. (Men only.)	
28. Contents of the following sections of the enlisted service record:	E-3
a. Record of Emergency Data.	
b. Enlisted Classification Record.	
c. Navy Occupation and Training History.	
d. Marks.	
29. Purpose of primary and secondary NEC codes	E-3
30. Meaning of following terms:	E-3
a. Accrued leave.	
b. Earned leave.	
c. Emergency leave.	
d. Excess leave.	
e. Advance leave.	
31. Personal services available to enlisted men and their dependents, including Red Cross and Navy Relief	E-3
32. Correct method of submitting a request through official channels	E-3
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* U.S. GOVERNMENT PRINTING OFFICE : 1959 O—508116